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VOLUME XIII NUMBER 6

THE PHYSICAL REVIEW

A JOURNAL OF EXPERIMENTAL AND THEORETICAL PHYSICS

CONDUCTED BY

EDWARD L. NICHOLS

ERNEST MERRITT, and FREDERICK BEDELL

LXX

DECEMBER 1901

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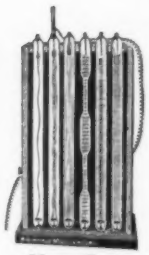

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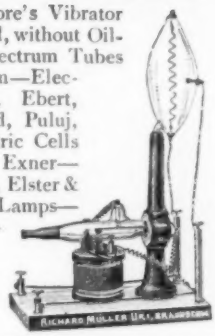

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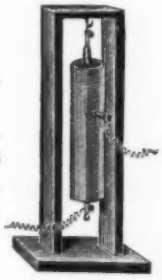

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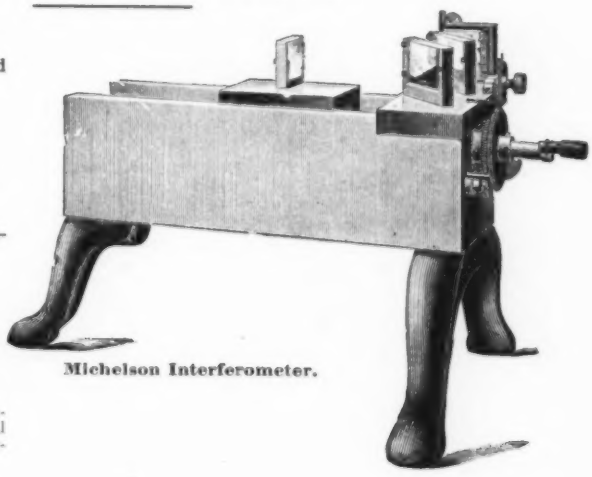

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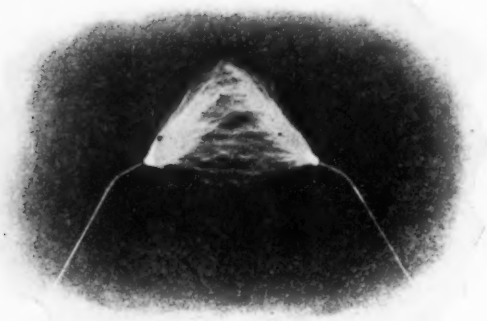

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THE

PHYSICAL REVIEW.

DISCHARGE OF ELECTRICITY FROM GLOWING PLATINUM AND THE VELOCITY OF THE IONS.[1]

BY E. RUTHERFORD.

THE fact that glowing bodies discharge positive and negative electricity with unequal facilities, has been shown by many observers. The most detailed examination of this subject has been made by Elster and Geitel.[2] They found that when a platinum wire was heated to a bright red heat, in an atmosphere of air or oxygen, at low pressure, a cold metal plate in its neighborhood discharged negative electricity more readily than positive. If, however, a thin platinum wire or carbon filament is heated in an atmosphere of hydrogen at low pressure, the cold plate discharges positive electricity more readily than negative.

The object of the present investigation was to test the validity of certain results obtained from a theoretical consideration of the conductivity of gases when the ionization was confined mainly to the surface of one electrode. A very simple means of obtaining strong surface ionization is to heat a platinum wire or plate to a red heat by an electric current, and this method has been employed in the course of the investigation. An account of the theory as given in a recent paper by the author,[3] in order to explain the differences observed in the value of the current through ionized gases when the

[1] A paper read at the Denver meeting of the American Association for the Advancement of Science, August, 1901.

[2] Wied. Annal., 37 and 38.

[3] Phil. Mag., August, 1901.

electric field was reversed. When these investigations were in progress C. D. Child[1] published a paper in which a similar theory was worked out and applied to determine the velocity of ions drawn from a flame and from a carbon arc.

A brief account of the theory will first be given and then a comparison between the theoretical and experimental results.

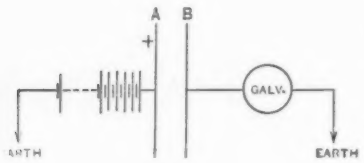


Fig. 1.

Let A (Fig. 1) be a platinum plate, the surface of which is to be a source of ionization; B, a metal plate, placed parallel to it and distant d apart. The plate A is connected to one pole of a battery of small accumulators, the other pole of which is to earth. The plate B is connected to earth through a sensitive galvanometer. Let v be the P.D. between A and B.

Suppose the plate A charged positively. When the plate A is heated to a red heat, a current is observed to pass through the galvanometer. In order to produce this current, positive ions, produced either from the heated plate or the gas in its immediate neighborhood, pass across from A to B.

Let i = current per sq. cm. through the gas.

n = number of ions per cc. at any point distant x from A.

e = charge on the ion.

When the current is steady, the same current passes over any any cross section between the plates,

$$i = - Kne\frac{dv}{dx},$$

where K = velocity of positive ion per unit potential gradient and $\frac{dv}{dx}$ is the electric force.

By Poisson's equation,[2]

$$\frac{d^2v}{dx^2} = - 4\pi ne.$$

[1] See J. J. Thomson, Phil. Mag., 47, p. 465.

[2] PHYSICAL REV., Feb. and March, 1901.

Eliminating n between these two equations, we obtain

$$2\frac{dv}{dx}\cdot\frac{d^2v}{dx^2} = \frac{8\pi i}{k} = a, \text{ say.}$$

Integrating

$$\left(\frac{dv}{dx}\right)^2 = ax + B.$$

Now B is the value of $\left(\frac{dv}{dx}\right)^2$ at the surface of the heated plate and can be made as small as we please by increasing the number of ions produced at the surface of the plate. This can be easily seen from first principles, for the higher the temperature the greater the number of ions produced per second and consequently the smaller the value of the electric field $\frac{dv}{dx}$ necessary to withdraw from the neighborhood of the plate, the number of ions requisite to convey the current. The potential gradient between the plates was experimentally examined and it was found that the slope of potential was extremely small near the heated plate and was greatest near the plate B. If the ionization is intense we can thus make B zero without any appreciable error.

Then

$$\frac{dv}{dx} = -a^{\frac{1}{2}}x^{\frac{1}{2}}.$$

Integrating between the limits 0 and d

$$v = -\tfrac{2}{3}a^{\frac{1}{2}}d^{\frac{3}{2}}$$

or

$$v = -\tfrac{2}{3}\sqrt{\frac{8\pi i}{k}}\cdot d^{\frac{3}{2}}$$

and

$$i = -\frac{9v^2k}{32\pi d^3}.$$

The ionization theory, applied to the question of the current between two parallel plates, when the ionization is powerful and confined mainly to the surface of one electrode, thus leads to the following conclusions :

1. The current is independent of the intensity of the ionization, *i. e.*, of the temperature of the plate, beyond a certain limiting value; for the equation, giving the current, does not involve the intensity of the ionization at the surface of the plate.

2. The current is directly proportional to the square of the voltage between the plates.

3. The current is directly proportional to the velocity of the ions and inversely as the cube of the distance between the plates.

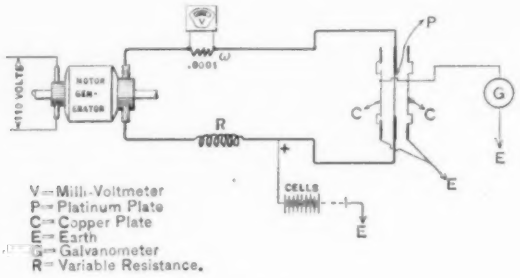


Fig. 2.

Experimental Arrangement.

The platinum foil, which served as a source of ionization, was rectangular in shape, 14 cms. long, 7.5 cms. wide, and .002 cm. thick. It was fastened at each end to solid copper plates by means of silver solder.

The upper plate was attached to a copper rod, through which the current entered, and the lower plate dipped freely into a mercury trough. The foil was thus always in a vertical plane and no correction was necessary for sag of the foil with rise of temperature. The experimental arrangement can be clearly seen from Fig. 2. The current was supplied from a motor generator, from which a current of 150 ampères, at 15 volts, could be readily obtained. The current was measured by a Weston millivoltmeter off a standard .0001 ω and could be varied by a low resistance rheostat in the circuit. The whole system was moderately well insulated and could be charged up to 600 volts above the earth, by means of a battery of small accumulators, one pole of which was connected to earth. The current was measured by means of a sensitive galvanometer between the

platinum plate and two vertical copper plates c and c, placed at equal distances from opposite sides of the platinum foil. In order to obtain a uniform electrostatic field these copper plates were surrounded by guard-rings and additional side plates were fixed near platinum plate and in the same vertical plane.

The galvanometer was always slightly disturbed by the magnetic field due to the large current circulating in the leads. This was compensated for by placing a coil of wire, shunted off the .0001 ω near the galvanometer.

The sensitive galvanometer employed was of about 100,000 ω resistance and gave a deflection of 1 mm. at about 2 meters distance for a current of $3.50\ 10^{-10}$ amps.

Experimental Results.

The platinum plate began to discharge positive electricity at a temperature just below a dull red heat. The deflection for a given P.D. between the plates increased rapidly with rise of temperature. The effect of increase of temperature of the platinum plate on the amount of current for a given P.D. varies with the distance between the plates. For a distance of 3 cms. and over, the current first increased rapidly to a maximum, remained practically constant over a short range, and then steadily diminished with increase of temperature to a white heat. For a distance of 2 cms. and under, the current first increased rapidly and then more slowly with rise of temperature, but did not pass through any maximum.

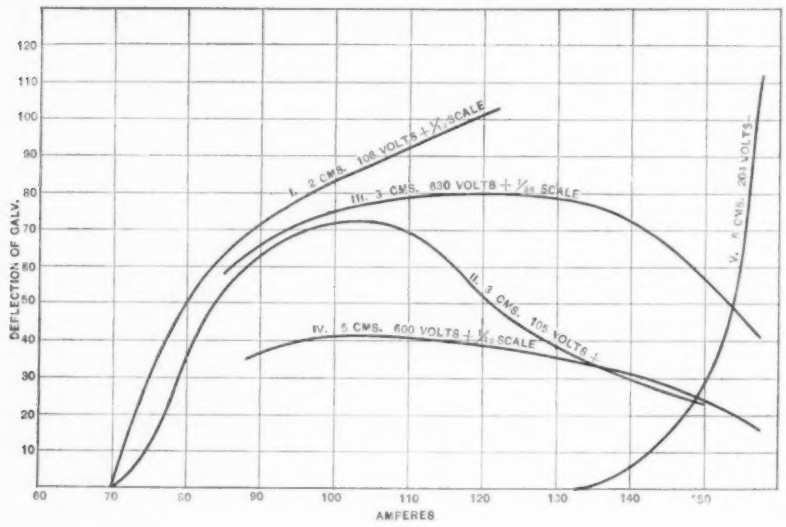
Curves I., II., III. and IV., Fig. 3, show the general nature of the results, where the ordinates represent current (on different scales) and abscissæ, ampères, through the platinum plate. The plate begins to discharge positive electricity at about 70 amèpres. For distances 3 to 8 cms. a practical maximum is reached for a current of about 100 ampères.

Between 2 and 3 cms. the curves change in shape.

The shape of the curves for a given distance between the plates was altered to some extent by increase of the P.D. between the plates.

According to the theory, already considered, we should have expected the current to reach a maximum for a given P.D. and

then remain constant, however much the amount of ionization at the surface of the plate was increased. In the experimental case, however, the theoretical conditions are not fulfilled. In order to increase the rate of production of ions, the temperature of the platinum plate is increased and the air between the plates is heated. Since the ions move faster in the heated gas and the current depends on the velocity of the carrier, it would naturally be expected that the current would first increase rapidly and then more slowly, as the temperature of the plate was raised. This is experimentally observed for a distance of 2 cms. and under.


DEFLECTION OF GALV.
AMPERES
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III. 3 CMS. 630 VOLTS + 1/10 SCALE
II. 3 CMS. 108 VOLTS +
IV. 5 CMS. 600 VOLTS + 1/10 SCALE
V. 5 CMS. 201 VOLTS

Fig. 3.

The explanation of the decrease of the current with rise of temperature for distances greater than 3 cms. will be given in detail later in the paper (page 329). It is there shown that the diminution is probably due to the presence between the plates of some slowly moving carriers.

Negative electricity was not discharged from the platinum plate till a white heat, with a maximum current of about 135 ampères. Over the wide range of temperature corresponding to the difference between the currents 70 and 135 ampères, positive electricity only can be discharged.

Variation of the Current with Voltage.

The current through the platinum plate was kept approximately constant at 100 ampères. This corresponds to the maximum current through the gas for the distance of 3 cms. and above. The current was found to vary approximately as the square of the P.D. between the plates.

Distance between platinum and copper plate, 2 cms.
1 mm. of scale $= 3.50\ 10^{-10}$ amps.

P.D. in Volts.	Deflect. of Galv. in mms.	$\frac{\text{I}}{\text{deflection}}$ volts.
26	27	.200
52	115	.206
104	470	.208
156	1150	.217
208	2178	.224
312	4540	.216
364	6120	.215
468	10340	.217
624	18800	.219

Suitable shunts to galvanometer were employed for the larger currents. In the third column is given the value of the square root of the deflection divided by the P.D. in volts. This should be a constant if the current is proportional to the square root of the voltage. The above results show that this is very approximately the case. The interpretation of the results for lower voltages is complicated by the P.D. between terminals of platinum plate due to the passage of the current through it.

Plates 3 cms. apart.

P.D. in Volts.	Deflection.	$\frac{\text{I}}{\text{deflection}}$ volts.
52	15	.074
104	63	.076
156	142	.076
208	267	.078
312	667	.080
468	1466	.082
624	2690	.083

In both these cases, the deflection increases slightly more rapidly than the square of the P.D. This is probably due to the fact

that the ions increase in size and thus diminish in velocity, the longer the time taken to travel between the electrodes. The results obtained for distances up to 8 cm. are similar to those given above.

Variation of the Current with Distance Between the Plates.

From the theory, the current between the plates for a given P.D. should vary inversely as the cube of the distance between them. This relation is, however, widely departed from in the experimental case.

The following table shows the way in which the current, for a temperature corresponding to about 100 amps., varies with the distance between the plates for a P.D. of 624 volts.

Distance d in cms.	Current i.	$i \times d^3$
2	18800	150,000
3	2690	72,600
4	835	53,400
5	296	37,000
6	156	33,700

The above values were taken from observations at different times and are only approximate.

The current thus falls off more rapidly than the inverse cube of the distance. The value id^3 should be equal if the ionic velocities are constant for different distances between plates. It will be shown later, however, that in consequence of the air being heated near the platinum plate, the velocity of the carrier is greater near the platinum plate and diminishes as we proceed from the plate.

The average velocity (as will be shown later) of the ion for the plate 2 cms. apart, is about 7.8 cms. per second, for a potential gradient of 1 volt per cm. and for 5 cms. 4.7 cms. per second. Since K is proportional to $\frac{id^3}{v^2}$, when K is increased, $\frac{id^3}{v^2}$ increases in like ratio.

The results on the variation of the current with voltage and the variation with distance between the plates, are thus in general agreement with the theory of ionization, taking into account the differences between the theoretical and experimental conditions.

The diminution of current with distances of 3 cms. and over for high temperatures, is, however, quite contrary to the result to be expected from the simple theory and has therefore been made a matter of detailed investigation.

The phenomena can be satisfactorily explained if we suppose that, above a certain temperature, the current is carried by two or more kinds of carriers, some of which move much slower than the others. Let us for simplicity suppose the carriers between the plates are of two kinds, but of the total current i per sq. cm. between the plates, the current i_1 is conveyed by carriers of velocity K_1 and the current i_2 by carriers of velocity K_2. Then $i = i_1 + i_2$.

$$\frac{d^2v}{dx^2} = -4\pi(n_1 + n_2)e,$$

where n_1 and n_2 are the number of ions of the two kinds at any point distant x from the platinum plate ;

$$i_1 = -K_1 n_1 e \frac{dv}{dx},$$

$$i_2 = -K_2 n_2 e \frac{dv}{dx}.$$

Therefore

$$\frac{i_1}{K_1} + \frac{i_2}{K_2} = -(n_1 + n_2)e \frac{dv}{dx},$$

or

$$2\frac{dv}{dx} \cdot \frac{d^2v}{dx^2} = 8\pi\left(\frac{i_1}{K_1} + \frac{i_2}{K_2}\right).$$

Integrating twice as before, and putting $\frac{dv}{dx} = 0$ at the origin, as in the simpler theory, we finally obtain,

$$\frac{i_1}{K_1} + \frac{i_2}{K_2} = -\frac{9v^2}{32\pi d^3}$$

or

$$\frac{i}{K_1}\left[1 + \frac{i_2(K_1 - K_2)}{iK_2}\right] = -\frac{9v^2}{32\pi d^3}.$$

For a given voltage and distance, the right hand side is a constant and the value of i depends on the value of the second term of the

left hand side of the equation. If K_2 be small compared with K_1, the value of the term may become considerable even though i_2 may be small compared with i_1. For example, if

$$K_1 = 100K_2$$

and

$$i_1 = 100i_2$$

the limiting value of the current i is only half of its value if no such slow moving carriers were present.

The effect of the presence of slow moving carriers between the plates can be readily shown by a simple experiment. The current between heated platinum plate and copper plate 3 cms. apart, was observed on the galvanometer. A slight current of tobacco smoke, or smoke from mouldering cotton waste, was allowed to pass between the plates. The current instantly fell to less than half its value. When the current of smoke ceased, the current immediately regained its former value. The explanation is simple. Some of the positive ions in their passage between the plates became attached to the large smoke nuclei, which in consequence of their size moved very slowly in the electric field. Although the number of such carriers was probably extremely small compared with the number of ions at any given time between the plates, the effect on the value of the current was very marked.

Some information as to the presence of slow moving carriers can be gained by directing a rapid current of air between the plates. In a special experiment, a current of about 100 ampères was kept through the platinum plate, which corresponded to about the temperature of the maximum current between plates 5 cms. apart. On directing a current of air from bellows between the plates the deflection of the galvanometer rose from 65 to 84 divisions and remained constant if current of air was kept constant. The current through the platinum plate was then raised to 150 ampères and the current without the blast fell to 30, and on directing a current of air of the same velocity as before between the plates, the current rose to 60. In the one case, the current increased twice and in the other, 1.3 times. The current of air was not sufficiently rapid to blow out between the plates many of the swifter moving ions, but even a

comparatively slow current of air increased the current quite appreciably, showing that some slow moving carriers were probably present at the lower temperature. The greater increase of current with the blast for the high temperature would show that more slow moving carriers were present between the plates than at a lower temperature. This is in agreement with the results on the decrease of current between the plates with temperature.

The shapes of the curves expressing the relation between current and ampères through the platinum plate (Fig. 2) are seen to depend both on the distance between the plates and the P.D. A few examples, sufficient to illustrate the general result, are given in the curves of Fig. 2. For a distance of 2 cm. and under, the current (curve I.) increased steadily with the temperature, whatever the voltage. For a distance of 3 cm. and over, the current always reached a maximum for a current of about 110 amps. and then diminished. The ratio to which the current was decreased by rise of temperature was smaller, the larger the P.D. acting. This is shown by the curves II. and III., for plates 3 cm. apart and 105 and 630 volts between the plates. For 630 volts, the current does not decrease so soon or so much as for 106 volts. For intermediate voltages, the general shapes of the curves are intermediate between curves II. and III.

The relation between temperature of the plate and the current for a given voltage receives a general explanation, if we suppose that the number of the slow moving carriers, appearing between the plates, increases with the temperature and the voltage, but that their number does not increase so rapidly as the current between the plates, which increases, as we have seen, nearly as the square of the P.D. This will suffice to explain the differences between the curves II., III. and IV. For a change of distance from 3 to 2 cm., the current increases over 10 times and in a greater proportion than the number of the slow moving carriers. The increase of velocity of the ions, due to the average rise of temperature of the gas with increase of current through the platinum plate, more than compensates for the increase of the number of slow moving carriers and the current consequently increases with rise of temperature of the platinum plate.

At the present state of our knowledge, no very definite explanation can be given of the origin of the slow moving carriers. As no sign of smoke or fumes could be seen rising between the plates, the action was not likely due to such nuclei. There are, however, two possible explanations of the presence of these large carriers. In the first place it is well known that a glowing platinum wire loses in weight. It is probable that this loss of weight is due to the disintegration of the surface of the platinum. The particles of metal shot off would probably be large compared with a molecule, and in their slow passage between the plates would, as in the case of the smoke nuclei, acquire a charge from the ions through which they move. This explanation would also serve to account for the diminution, in some cases, of the current with rise of temperature where the plate is negatively charged (see Fig. 8, curves for 53 and 102 volts).

On the other hand there is considerable evidence that in the discharge of electricity by flames and glowing platinum, the ions between the plates are not all the same size.

Whether these carriers are initially unequal in size or have different powers of acting as nuclei for the condensation of matter around them is difficult to settle experimentally. There seems to be little doubt that some ions, for example those present in flame gases, increase rapidly in size as the flame gases diminish in temperature. The results of Maclelland[1] on the velocity of ions drawn from a flame point strongly to this conclusion.

We have also the well-known fact that negative ions produced by Röntgen rays increase in size when the gas in which they are produced is saturated with water vapor.

DISCHARGE OF NEGATIVE ELECTRICITY.

Negative electricity could not be discharged for low voltages until the platinum plate had nearly reached a white heat with a current of about 135 ampères. The relation between current and P.D. could only be examined over a range of 135 to 165 ampères, which was the maximum current that could be employed in the experiments. The results are embodied in curves in Figs. 4 and 5.

[1] Proc. Roy. Soc., 1899.

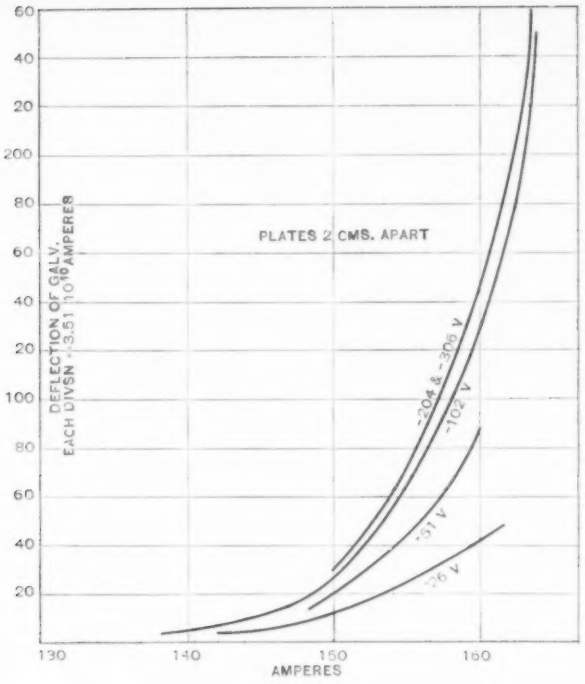
PLATES 2 CMS. APART
DEFLECTION OF GALV.
EACH DIVSN = 3.51 10⁻⁶ AMPERES
-204 & -306 V
-102 V
-51 V
-26 V
AMPERES

Fig. 4.

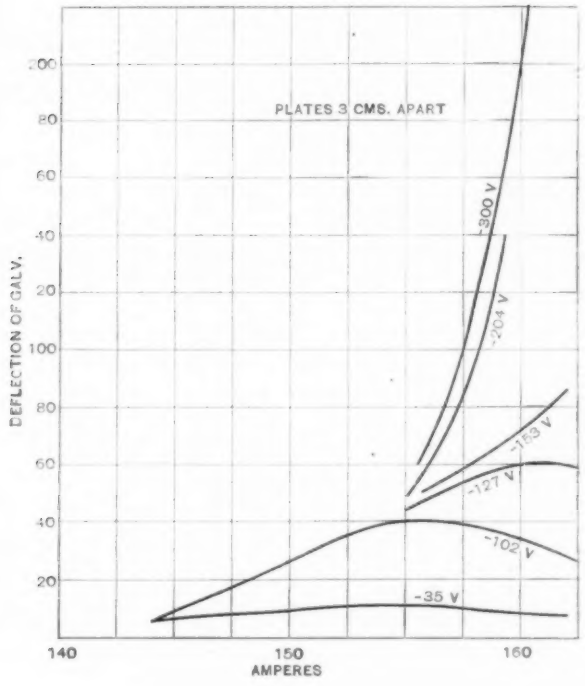
PLATES 3 CMS. APART
DEFLECTION OF GALV.
-300 V
-204 V
-153 V
-127 V
-102 V
-35 V
AMPERES

Fig. 5.

In Fig. 4 the results are given for a distance of 2 cms. between the plates for voltages varying from −26 to −306 volts. It will be observed that in all cases the current increases rapidly with increase of temperature. There is very distinct evidence that for a given temperature the current reaches a maximum and is not much affected by increase of voltage from −200 to −300 volts, showing that all the negative ions produced are carried across. As a very slight variation of the temperature causes a very large increase in the current, the results given for comparison are only approximate.

For plates 3 cms. apart a very distinct difference is observed. In Fig. 5 the results are given for P.D. ranging from 53 to 300 volts. From −53 and to −102 volts, the current reaches a maximum and then decreases with rise of temperature, and, in this respect resembles curves for the positive discharge. For 127 volts P.D., the current is nearly constant at its higher portions, while from 153 to 300 volts the current is found to increase continuously and rapidly with increase of temperature. The temperature of the platinum plate has not been pushed high enough to obtain sufficient ionization at the surface for the current, due to negative ions, to vary as the square of the P.D. For this reason no attempt has been made to compare the velocity of the positive and negative ions.

Temperature Gradient Between Plates.

In the experimental arrangement the plates were vertical and exposed freely to the air on all sides. The average temperature of the gas between the plates is shown in Fig. 6, for distances of 2 and 3 cms., when a current of 124 amps. was passing through the plates, which corresponded to a bright red heat.

The temperatures were determined by a platinum rhodium thermocouple, with a special apparatus, designed and calibrated by H. M. Tory, M.A., of McGill University, for the measurement of high temperatures.

It was observed that the platinum plate was appreciably cooled by conduction at the point of contact of the junction with its surface. For this reason the indicated temperature of the plate was much too low. For a distance of 2 cms. between the plates, the indicated temperature of the platinum plate was 991° C., for a current of 134

amps., and was probably at least 100° C. too low. The temperature fell extremely rapidly near the surface of the platinum plate, became approximately constant for some distance midway between the plates, and increased slightly near the copper plate. This is to be expected since the copper plate was heated by radiation to a higher temperature than the surrounding air. The lowest temperature observed for the air between the plates was 169° C. for 3 cms. apart and 281° C. for 2 cms. With increase of distance the average temperature between plates steadily decreases.

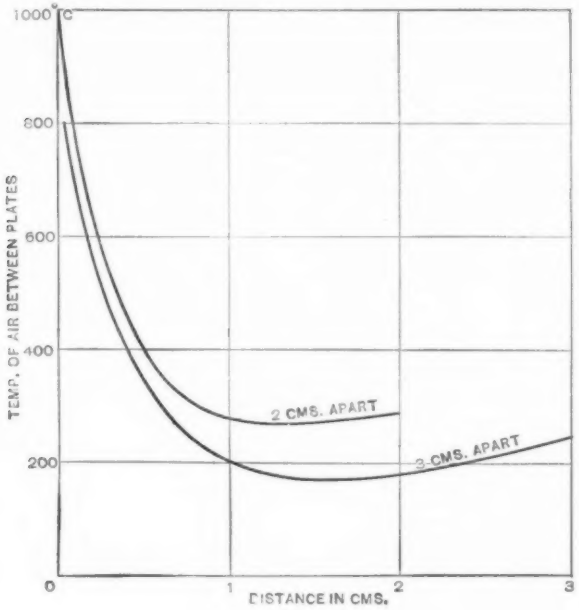

Fig. 6.

Velocity of the Ions.

From the theory discussed in the beginning of the paper, the velocity of the positive ion is given by

$$k = \frac{32\pi i d^3}{9v^2}.$$

At first sight this equation offers a simple and fairly accurate method of determination of the velocity of the ions, since i, the limiting current (which is measured by a galvanometer or electrometer),

is independent of the intensity of the ionization at the surface of the platinum plate, and the quantities v and d can be accurately measured. The current has been shown to vary very approximately as the square of the P.D., so that the velocity deduced is independent of the voltage employed.

The following table is an example of the determination of velocities for distances between the plates varying from 2 to 7 cms., by means of the theory.

Distance Between Plates.	P.D. in Volts.	Deflection of Galvanometer.	Calculated Velocities for 1 Volt per cm.
2	52	103	5.5 cms. per sec.
3	103	68	3.17 " "
3	155	155	3.19 " "
4	155	53	2.59 " "
4	256	150	2.69 " "
5	255	63	2.20 " "
5	306	90	2.20 " "
7	282	24	1.90 " "

Current through platinum plate about 110 amps.
1 scale division of galvanometer $= 3.50\ 10^{-10}$ amps. $= 1.05$ E. S. units per sec.

Area of each plate surrounded by guard ring, 96 sq. cms.

The current observed, except for distance of 2 cms., was a maximum. In the above table the value of i, the current per sq. cm., is equal to the deflection divided by 192, since the current was measured to two plates, 96 sq. cms. in area, at equal distances on each side of the platinum plate. In order to calculate the velocity, i and V are expressed in electrostatic units, and the value K is then given for a potential gradient of 1 E. S. unit per second. The velocity for 1 volt per cm. is obtained by dividing this value by 300.

It will be observed that the calculated value of the velocity is greatest when the plates are closest together and gradually diminishes with the distance. For a distance of 2 cms. between the plates, the gas through which the ions travel is at a much higher average temperature than for a distance, say, of 7 cms.

A very important question now arises whether we are justified in assuming that the calculated value of the velocities of the ions given above represents even approximately the average velocity of the ions through the gas. The theory is based on the supposition that the

ions are all of the same kind and size and that the velocity is unaltered in passing from one plate to the other. These conditions are, however, widely departed from in practice. Since the temperature of the gas between the plates is greatest near the platinum surface and gradually falls off to the copper plate, a given ion will decrease in velocity, for a given potential gradient, as it passes from the hot to the cold plate. The experiments of Maclelland [1] also show the velocity of the ions drawn from flame gases diminish rapidly as the temperature of the gas, through which they move, decreases. This decrease of velocity is much greater than can be accounted for by the lowering of the temperature of the gas and seems to be due to an actual increase of size of the ion. It is probable that the ions from a heated platinum surface will also show similar behavior.

It will also be shown later that the velocity of the ions at a given point of the gas is not a constant, but varies between fairly wide limits. We have also seen that some very slow moving carriers are present between the plates, the effect of which is in some cases to greatly reduce the current.

Taking all these divergences between the actual and theoretical conditions into consideration, it cannot be assumed without a special investigation that the velocities of the ions tabulated from the equation represent even approximately the true values.

Direct Determination of Velocity of the Ions.

In order to settle the amount of agreement between the calculated and actual velocities, a direct method of measuring the velocity of the ions was employed.

The method is identical in principle with that previously employed by the author [2] to determine the velocity of the negative ion produced by ultra-violet light falling on a negatively electrified surface.

A direct P.D. was changed to an alternating P.D. of known frequency by means of a suitable revolving commutator. This alternating P.D. was applied to the platinum plate. Suppose the current through the platinum plate is large enough to produce a

[1] Proc. Roy. Soc., 1899.
[2] Proc. Camb. Phil. Soc., 1898.

large supply of positive ions, but not large enough to discharge negative electricity. The instant the platinum plate is charged positively, the positive ions start to travel towards the copper plate. If the sign of the platinum plate is reversed before the leading ions reach the negative electrode, the positive ions travel back again and no current passes through the galvanometer.

The ions are thus alternately advancing and retreating during each successive change of the electric field.

Let d be the smallest distance between the plates such that for a P.D., v_0, no ions reach the copper plate. The electric force between the plates (assumed uniform) is $\frac{v_0}{d}$ and the distance d passed over in the time T of a half alternation is given by $d = \frac{v_0}{d}$ K.T. where K is the velocity of the ion per unit potential gradient; therefore

$$K = \frac{d^2}{v_0 T}.$$

In the special case we are considering, the electric field is not uniform. A special series of experiments showed that the potential gradient between the plates was very approximately the same as that deduced from theory.

We therefore have

$$\frac{dv}{dx} = -a^{\frac{1}{2}}x^{\frac{1}{2}},$$

and

$$v_0 = -\tfrac{3}{2}a^{\frac{1}{2}}d^{\frac{3}{2}},$$

therefore

$$\frac{dv}{dx} = \tfrac{3}{2}\frac{v_0 x^{\frac{1}{2}}}{d^{\frac{3}{2}}}.$$

The time dt taken to pass over a distance dx is given by

$$dt = \frac{dx}{K\frac{dv}{dx}} = \tfrac{2}{3}\frac{d^{\frac{3}{2}}}{Kv_0 x^{\frac{1}{2}}}\,dx.$$

Therefore, if in time T of a half alternation, the ions can just travel over a distance d, by integration we obtain

$$T = \tfrac{4}{3}\frac{d^2}{K v_0}$$

or

$$K = \tfrac{4}{3}\frac{d^2}{v_0 T},$$

or for a given P.D. between the plates, the time taken for an ion to travel between them is $\frac{4}{3}$ that taken if the field were uniform.

In experiments on the velocity of the negative ions produced by ultra-violet light, the alternating E.M.F. of the Cambridge town mains was employed. It is, however, much more satisfactory to commute a direct E.M.F., as in that case the period of commutation is under control and the P.D. is constant during each half alternation. The commutator employed was a two part one of diameter 6.3 cms., driven by an electric motor. The insulation gap between each segment was .5 cm. so that the P.D. was applied during .95 of the time of alternation.

The speed of rotation of the commutator was determined by means of an apparatus devised by Prof. R. B. Owens, of McGill University. The armature of a small magneto-machine rotated on a continuation of the axis of the commutator. The E.M.F. generated, which was measured by a Weston voltmeter, was directly proportional to the speed. This apparatus is very advantageous for reading speeds accurately at a distance.

In the practical determination of the velocities, it was found convenient to keep the plates at a fixed distance apart and then decrease the P.D. until the point of no appreciable current through the galvanometer for a known speed of the commutator. Theoretically, if the ions all have a uniform velocity, the P.D. for which no ions reach the plate should be sharply defined. This was observed to be the case in the measurement of the negative ions produced by ultra-violet light, but in the first experiments it was found that the P.D. could not be adjusted accurately, but that a slight current passed through the galvanometer over a considerable range of voltage.

This result is not surprising when we consider that the ions are probably growing in size with time and thus move more slowly on their return journey. Some of the ions, therefore, will be unable

to return to the platinum plate in the time of a half alternation. If this process continues, in the course of a large number of alternations, these ions will reach the copper plate and a current will be indicated on the galvanometer with a lower voltage than is actually necessary to carry over the original ion from the platinum to the copper plate.

This difficulty, however, can be overcome very simply. In series with the alternating E.M.F. $\pm E$ a battery of accumulators is placed of E.M.F. E_1 less than E. The P.D. acting for one-half alternation is $E + E_1$ and for the other half $E - E_1$. If the platinum plate is charged positively to a P.D. $E - E_1$, the returning ion moves in an electric field approximately $\frac{E + E_1}{E - E_1}$ times that for the outgoing ion. By adjustment of the values of E and E_1, the value $E - E_1$ can be made as small as we please compared with $E + E_1$, so that all the ions which set out during the one-half alternation are swept back during the next half. Under these conditions it was found that the value of the P.D. necessary to give no current could be adjusted without certain well-defined limits.

The following is an example of the determination of velocity of ions for plates 3 cms. apart, with a current through platinum plate of 105 amps. In this case, the deflection of the galvanometer was too small to observe with accuracy, so that a one-third microfarad condenser, in parallel with the copper plate, was charged up for 30 seconds and then discharged through the galvanometer.

P. D. +	P. D. −	Deflection.	Time.
46 volts	143 volts.	0	30″
48.6 "	146 "	1.5	30″
56 "	153 "	8	30″
65 "	162 "	18	30″
77 "	173 "	60	30″

Commutator made 750 revolutions per minute.

Time of application of P.D. was .0380 second, correcting for insulation distance between the segments.

Taking 46 volts as the minimum positive potential for no current and substituting in the formula

$$K = \tfrac{1}{3} \frac{d^2}{V_0 T}$$

we obtain $K = 7.9$ cms. per second as the maximum velocity of the ions between plates 3 cms. apart. It will be observed from the above table that the P.D. sweeping back the ions to the platinum plate is between 2 and 3 times as great as the P.D. which moves them from the platinum plate. In this way it is assured that all the ions which do not reach the copper plate are swept back to the platinum surface during the succeeding half alternation. Now the steady current for + 43 volts gave a throw in the galvanometer of 156 divisions when the condenser was charged for 30 seconds. This would correspond to a deflection $\frac{1}{2} \times .95 \times 156 = 74$ if all the ions starting out from the platinum plate during each half alternation reached the copper electrode. Assuming the current proportional to the square of the P.D., it can be readily calculated that for the voltages 48.6, 56, 65, 77, the ratio of the number of ions starting from the platinum plate which reach the copper plate, is .015, .07, .13, .28, respectively.

Taking as data that for 77 volts, .28 of the number of ions reach the copper plate, a rough average of the velocity of the ions can be deduced. For .28 of the time .038 second of a half alternation, ions reach the copper plate. The time taken for ions to cross between the plates is thus $.72 \times .038$ second, *i. e.*, .027 second. The average velocity is thus 5.8 cms. per second.

In a similar way it was found that the minimum voltage to carry over ions for a distance of 2 cms. for 1,000 revolutions per minute of the commutator, was 14.5 volts. The maximum velocity for this distance, 2 cms., is thus 13 cms. per second. This result can, however, be considered only as a rough approximation on account of the uncertainty of determining the actual positive potential of different portions of the platinum plate. It obviously varies from one end to the other on account of the P.D. sending the heating current through it.

The following method was employed to determine the average velocity of the ions between the plates.

A steady deflection corresponding to V volts between the plates was observed. The commutator was then slowly rotated and the

deflection fell slightly below one-half its value. Theoretically it should fall to ½ × .95 of its value and this was experimentally observed to be the case. On increasing the speed of rotation, the deflection steadily diminished. Let D_1 be the deflection for a period T of half alternation, and D the deflection for a very slow rotation of the commutator. The ratio of the number of ions reaching the copper plate is $\frac{D_1}{D}$ of the total starting out from the platinum surface, and if t be the time taken for the ions to cross over between the plates

$$.95T(1 - \frac{D_1}{D}) = t.$$

The velocity of the ions is then determined by substituting in the equation of velocities and we obtain

$$K = \tfrac{4}{3}\frac{d^2}{V \times .95T\left(1 - \frac{D_1}{D}\right)}$$

Using this method, a large number of determinations of velocities were made for distances 2, 3 and 5 cms., for different periods of alternation and different voltages. The mean of these values is included in the following table.

Velocity in cms. per second for 1 *volt per cm.*

Distance.	Maximum.	Average	Calculated.
2	13	7.8	5.5
3	7.9	5.8	3.2
5	—	4.7	2.2

The maximum velocity for a distance of 5 cms. was not determined, as the commutator sparked across before sufficient voltage could be employed to make sure of sweeping back the ions on their return journey. The current through the platinum plate, in all these cases, was kept constant at about 100 ampères, which corresponded to the temperature of maximum current at all distances except 2 cms.

It was experimentally observed that for a given distance the velocity of the ions increased with increase of temperature of the platinum plate, although the actual current observed through the galvanometer was diminished.

The results obtained from the direct measurement of the velocity of the ions may be summarized as follows:

1. The velocity of the positive ions drawn from glowing platinum is not a constant for given conditions, butmay vary within wide limits.

2. The velocities of the ions increase with increase o fthe temperature of the gas through which they pass.

3. The velocities calculated from the theoretical formula are too small. For 2 cms. distance between the plates the difference between the theoretical and experimental values is not large, but the difference increases with distance apart of the plates. For 5 cms. the calculated velocity is less than one-half of the average velocity.

The final conclusion we may draw from the results is that the velocity of the ions deduced from measure of the limiting current does not necessarily represent the average velocity and is much less than the maximum value of the velocity.

During the course of the investigation two papers appeared by C. D. Child, in the PHYSICAL REVIEW (February and March, 1901). In these papers the velocity of the positive and negative ions drawn from the flames and the arc have been determined by direct measurement of the current, using the theory given in the early part of the paper.

His results show clearly that the current varies approximately as the square of the voltage, and falls off more rapidly than the inverse cube of the distance. The diminution of the current with distance in the case of flames is not, however, so rapid as in the case of glowing platinum.

It will be of interest to compare the values of the velocity of the positive ions drawn from flames and from glowing platinum. For purposes of comparison we will give the "calculated" values of the velocities of the positive ions in the two cases:

Ions Drawn from Flame.		Ions Drawn from Glowing Platinum.	
Distance from Edge of Flame.	Calculated Velocity of Positive Ion.	Distance Between Plates.	Calculated Velocity Positive Ion.
1 cm.	2.85 cms. per sec.	2	5.5 cms. per sec.
2 cms.	2.27 " " "	3	3.18 " " "
4 "	2.21 " " "	4	2.64 " " "
6 "	2.00 " " "	5	2.20 " " "
8 "	1.45 " " "	7	1.90 " " "

The calculated velocities of the positive ion in the two cases are thus not very different for distances of 4 to 7 cms. The velocity of the flame ions is, however, considerably smaller for distances of 2 to 4 cms.

We have shown, however, that the calculated values given above for the platinum ions are far too small on account of the divergences between experimental and ideal conditions. The method employed by Child is a very simple and accurate one of determining velocities, provided the ions all travel with the same velocity, *i. e.*, are all of the same size. The presence, however, of some slow moving carriers between the electrodes may diminish the value of the current and the resultant calculated velocity may be much too small. Whether such slow moving carriers are produced in the case of flames as in the case of glowing platinum cannot be definitely answered without a special investigation. The presence of even a small number of large nuclei, such as are produced by smoke or fumes, tend to make the calculated velocities too small. For these reasons the measurements of velocity of the ions close to the electric arc must be interpreted with great caution.

MACDONALD PHYSICS BUILDING,
McGILL UNIVERSITY, July 1st.

A SPECTROPHOTOMETRIC COMPARISON OF THE RELATIVE INTENSITY OF LIGHT FROM CARBON AT DIFFERENT TEMPERATURES.

By Ernest Blaker.

FOR many years the idea advanced by Draper,[1] that all solid bodies, when heated, begin to give off light at the same temperature, that the rays first emitted were dull red and as the temperature was raised the shorter wave-lengths were added in succession, was accepted. E. Lecher[2] showed this to be not true and H. F. Weber[3] made an investigation of the subject in which it was shown that in general Draper's views would not hold. Weber's observations on carbon in the form of a glow lamp show that red does not appear first, but that to the unaided eye first appears a misty indistinct gray light, which is followed, as the temperature rises, by a series of characteristic changes before there is any appearance of red; passing through an ashen gray, then a pale yellow. The emission then changes to a bright yellow gray and the next addition is of an uncommonly bright red, which is intermittent at first, then is steady with no more flickering, being a fiery red. With rising temperature the light becomes orange, yellow, yellowish-white, then white. In studying the spectrum of the carbon filaments in the first stages of incandescence, Weber found the misty gray light to appear in that portion of the spectrum that is occupied by yellow and light green when the temperature was higher. With increasing current in the lamp, the gray band had a middle of yellowish-gray, shaded off at the ends into dull gray. At the time that the red flicker appears to the unaided eye the spectrum shows a delicate band of red on one edge and almost immediately a weak grayish-green border on the other side. The spectrum broadens out both ways with more current and when the center is a bright

[1] Draper, Phil. Mag., May, 1847, pp. 345–360.
[2] Lecher, Wied. Ann., No. 32, 1887, p. 256.
[3] H. F. Weber, Wied. Ann., No. 32, 1887, pp. 256–270.

yellow gray it extends from the middle of the red into the blue. Then with a yet further increase of temperature the whole spectrum presents itself.

Further heating increases the intensity of the light for all wave-lengths, but the wave-lengths of higher frequencies, as has been shown by Nichols and Franklin,[1] show the greatest increase. That this rate of change is not continuously greater toward the shorter wave-lengths, has been noted by Dr. Nichols,[2] and it was the purpose of the investigation herein described to obtain new data upon this subject.

TEMPERATURE OF GLOWING CARBON.

The lowest temperature at which the light emitted by carbon was studied in this investigation was such that in the longest red rays used the color was very dull, and no reading could be made for wave-lengths shorter than .470 μ.

The amount of light given off at certain temperatures was for some time simply a guess. M. Lucas[3] has made measurements of the temperature of glowing carbon, based on relations between resistance of the carbon and the current passing through it, and on that between resistance and temperature. In the special case treated, he found the temperature to be a simple function of the current. Lucas also measured the intensity of the light emitted.

H. F. Weber[4] has, on theoretical grounds, arrived at a relation between the radiation from incandescent carbon and its temperature, and has made many experimental determinations of the constants of the relation. His results, however, are thought to be too low.

M. Le Chatelier[5] has measured the temperature of incandescent lamps by a photometric comparison and has given his results in terms of the ratio $\frac{R_\theta}{R_0}$, where R_θ is the resistance of the lamp at a temperature θ and R_0 is its resistance cold.

M. P. Janet[6] has indicated how the temperature of incandescent

[1] Nichols & Franklin, Amer. Jour. Sci., 3d series, Vol. 38, 1889, pp. 111–115.
[2] Nichols, PHYSICAL REVIEW, Vol. XIII., p. 65, 1901.
[3] M. Felix Lucas, C. R., No. 100, 1885, pp. 454–456.
[4] H. F. Weber, PHYS. REV., Vol. II., 1894, pp. 112–121, 197–210.
[5] M. Le Chatelier, Jour. de Phys., 3d Serie, Vol. I., p. 203.
[6] M. P. Janet, C. R., No. 123, 1896, pp. 690, 691.

carbon may be obtained, based on the mean specific heat of carbon as determined by Violle,[1] and later[2] has given some determinations on four different lamps, expressing results in terms of $\frac{R_\theta}{R_0}$ for purposes of comparison with the results of Le Chatelier. In three of the lamps the values obtained are very close to values obtained by plotting Le Chatelier's results and interpolating. The average of these three gives a temperature of 1620° C. for a value of $\frac{R_\theta}{R_0}$ equal to .53 and the interpolation gives a value of 1600° C. for the same value of $\frac{R_\theta}{R_0}$. Using Le Chatelier's results as a basis, the temperature of the carbon filament, when there was a difference of potential of sixty volts between its terminals, was 1738° C., the

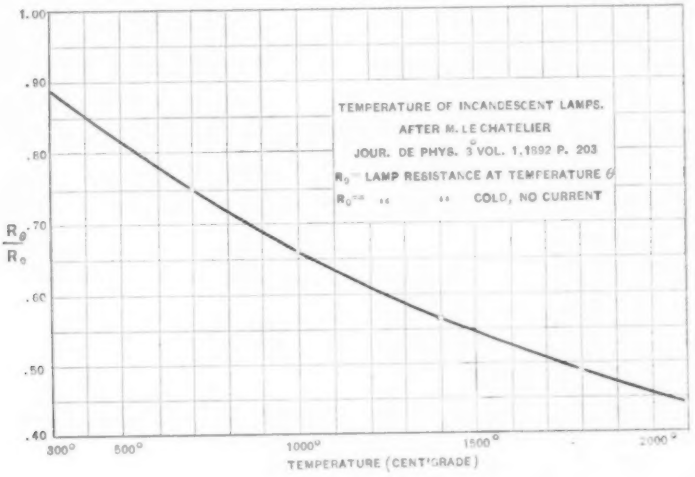

Fig. 1.

power loss in the lamp being 1.95 watts per candle. Lucas's results, reduced, give a temperature of about 1857° C. for the same power development and the mean of several results of Weber give a temperature of 1635° (abs.). Abney and Festing[3] conclude that the temperature appears to be nearly a simple function of the re-

[1] M. J. Violle, C. R., No. 120, 1895, pp. 868–869.

[2] M. P. Janet, C. R., No. 126, 1898, pp. 734–736.

[3] Abney and Festing, *Phil. Mag.* (5), No. 16, Sept., 1883, p. 225.

sistance, with which Le Chatelier's results applied to this experiment seem to agree. The results of Le Chatelier have been used as a basis for temperatures in this work, representing something near the truth.

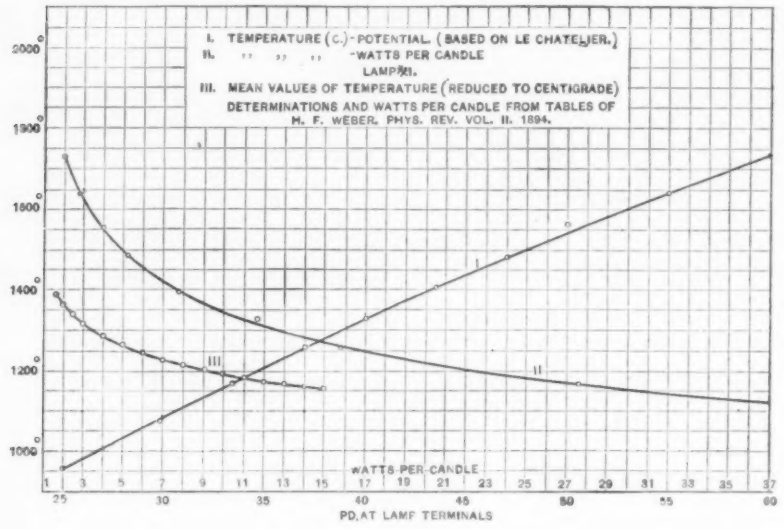

Fig. 2.

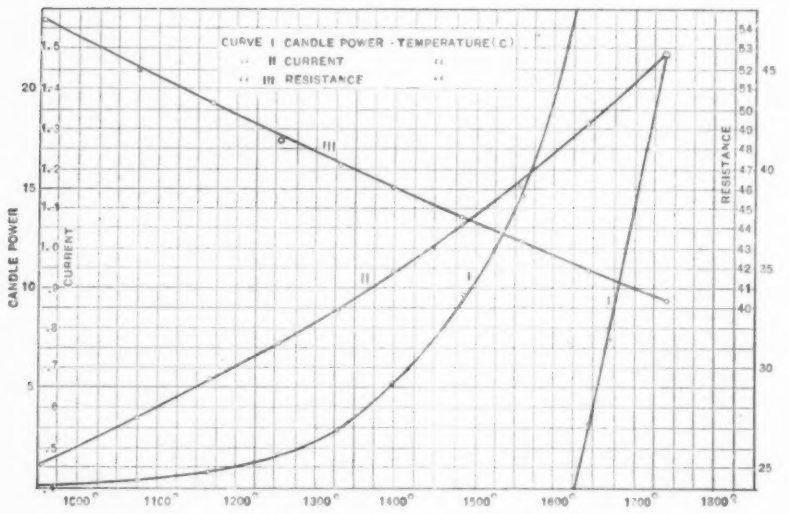

Fig. 3.

The curve in Fig. 1 shows the temperature of incandescent lamps plotted with $\frac{R_\theta}{R_0}$ from Le Chatelier's determination; Fig. 2 contains two curves showing (I.) the relation between potential differences at lamp terminals and temperature and watts per candle of the test lamp used in the measurements to be described in this paper, based on Le Chatelier's values; (II.) the temperature, watts per candle curve for the same lamp. A curve showing the relation between temperature and watts per candle as deduced from the mean of values taken from the data of several tests by Weber is given in the same figure (curve III.).

Fig. 3 shows the relation between the candle power, current and resistance of the test lamp and its temperature; the scale of temperatures being that derived from the determinations of Le Chatelier.

The following table gives the data upon which the curves relating to the test lamp were based:

TABLE I.

(*Test lamp No. 1.*)

V	I	R_θ	$\frac{R_\theta}{R_0}$	θ°C.	C. P.	W	$\frac{W}{\text{C. P.}}$
24.85	.456	54.5	.673	954		11.32	
29.90	.575	52.0	.642	1075	.33	17.18	52.
33.4	.668	50.15	.619	1168	.81	22.31	27.55
37.0	.763	48.49	.599	1255	1.8	28.24	15.7
40.0	.846	47.22	.583	1328	2.92	33.84	11.59
43.5	.943	46.02	.568	1398	5.25	40.93	7.8
47.0	1.055	44.55	.550	1484	9.62	49.59	5.16
50.0	1.16	43.29	.535	1559	14.63	58.00	3.96
55.0	1.31	41.89	.519	1643	27.00	72.05	2.67
60.0	1.48	40.54	.501	1738	45.60	88.80	1.95

$R_0 = 80.96$ *ohms at* 18° *C.*

APPARATUS AND ITS ARRANGEMENT.

The voltmeter used in this work was a large standard Weston instrument with a 150-volt, and a 3-volt scale. It was carefully calibrated for the 150-volt scale by a potentiometer method, balancing a standard Clark cell around a known resistance and then calculating the fall of potential through another known resistance, about which the voltmeter was shunted.

To measure the current, a standard Weston milli-voltmeter, with shunt box, was used. It was calibrated for two shunts; one using the one-ampère scale, and the other for the five-ampère scale, by placing it in series, first with a standard Hartmann and Braun ohm and then with a standard tenth ohm (H. & B.) around which was shunted the standard voltmeter, mentioned above.

In pursuing this investigation a Lummer-Brodhun spectrophotometer[1] was used. It consists of two collimator tubes at right angles to each other, the path of light from one source being directly through a glass cube, the path of light from the other source entering the cube and being reflected at a silvered surface within the cube in such a manner that it has the same length of path in the cube, and passes out of the cube parallel with and in the same vertical plane with the first ray, whence they are dispersed by a flint glass prism and may be examined in the telescope in juxtaposition. The instrument was supplied with two arms fastened rigidly to the base of the instrument, one being placed directly beneath and parallel with the axis of each collimator. On these arms two sources of light were placed at equal distances of 22.6 cm. from the collimator slits. One source was the standard of comparison, a flat acetylene flame from a Naphey burner, in front of which was placed a screen in which was a circular opening of 2.5 mm. radius, over which was placed a piece of glass from an incandescent lamp globe of the same type of lamp which was used as a source of incandescent carbon, on the other arm. The lamp used was one with a short thick gray carbon filament of the "hair pin" type, made to be used at 50 volts pressure. A screen was placed in front of this lamp cutting off all light from the collimator slit excepting that from a straight portion about two centimeters long, care being taken that the portion of the filament used be parallel with the axis of the slit. The instrument was so set up that this lamp was at one end of a thousand part photometer bar, at the other end of which was placed a secondary standard 16 c.p. fifty-five-volt lamp, which was used throughout below normal pressure the current being furnished by storage cells. The voltage was carefully adjusted each time the standard was used, to 50 volts. This secondary standard was

[1] Zeit. für Inst., No. 12, 1892, pp. 132–139.

standardized by comparison with an amyl-acetate lamp. The acetylene flame was used at a constant pressure throughout the work, of 7.35 cm. of water; the acetylene being produced by using commercial calcium carbide. The gas, as tested by Mr. Rands, was about 98.7 pure. For the lamp being tested, the current was furnished by a storage battery.

Outline of Method.

The order of experimentation was as follows: The test lamp was brought up to the desired brightness and its candle power measured by comparison with the standard lamp, using a Bunsen photometer; then with a definite opening of collimator slit the collimator slit of the standard acetylene source was varied until, for the rays being compared, the intensity was alike for both sources. In nearly all cases at least ten readings were taken for each wave-length. Eleven wave-lengths were compared, extending almost the whole length of the visible spectrum. In some instances whole sets were run over again as a check. In order that the test lamp might last throughout the experiment, it was used with small voltages and currents first, then gradually increased. The lamp was not used for a very long time at voltages near the normal and consequently did not deteriorate appreciably in candle power until used at sixty volts. Then it fell off about seven per cent. in candle power between the beginning and end of the run at that voltage. In this run the red end of the spectrum was tested first. All readings were corrected for slit width from curves based on those obtained by C. V. Capps[1] for a sixty-degree flint glass prism; both prisms being furnished on instruments made by Schmidt and Haensch.

The intensity of the acetylene source was taken as unity for the luminous intensity of the various wave-lengths and from the data obtained were drawn, for each wave-length, "isochromatic curves," using in one case, intensities and temperatures (C) for coordinates and in the other case log. of intensities and reciprocals of temperatures (abs.). (See Figs. 4 to 14 inclusive.) The intensity-temperature curves would have the same form whether plotted with the temperatures, centigrade or absolute, since the difference would be

[1] Capps, Astrophysical Journal, Vol. II., January, 1900, pp. 25–35.

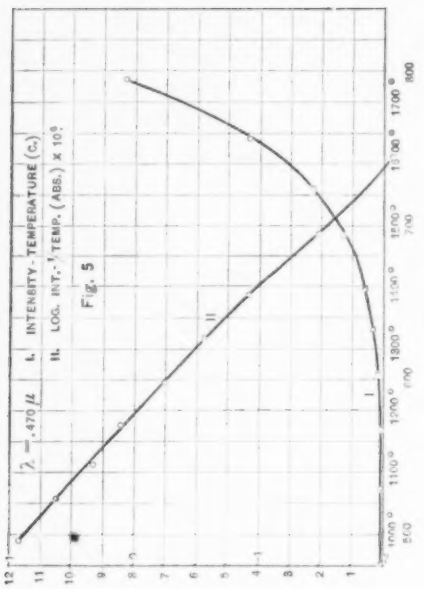

Fig. 5.

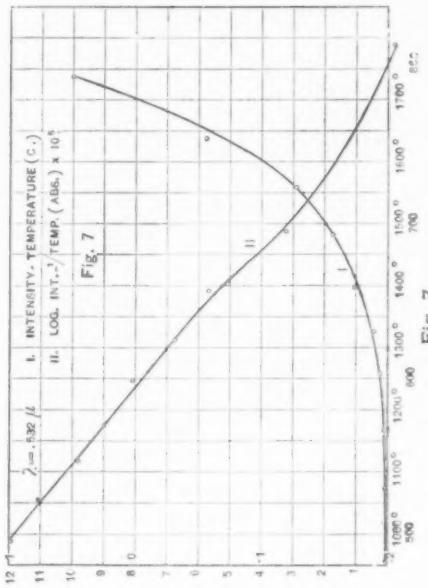

Fig. 7.

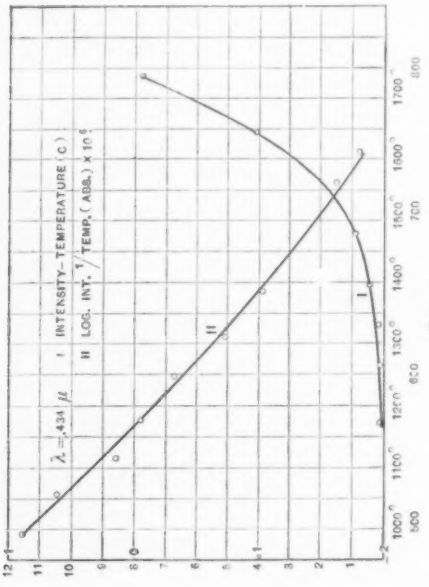

Fig. 4.

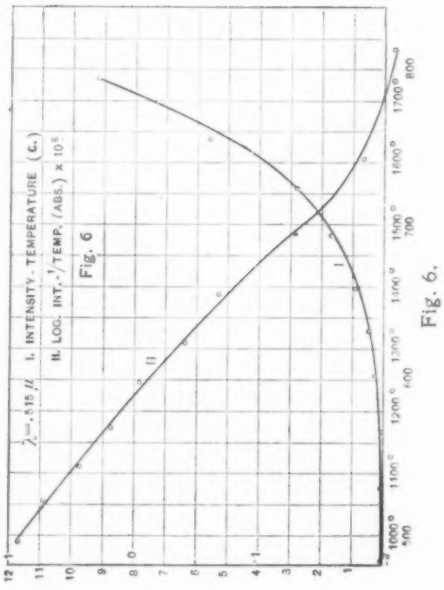

Fig. 6.

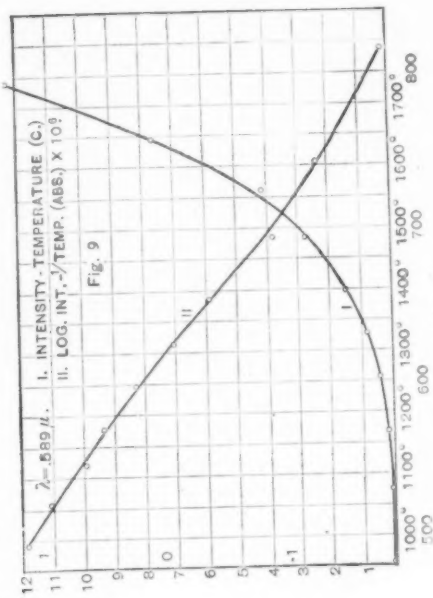

Fig. 9.

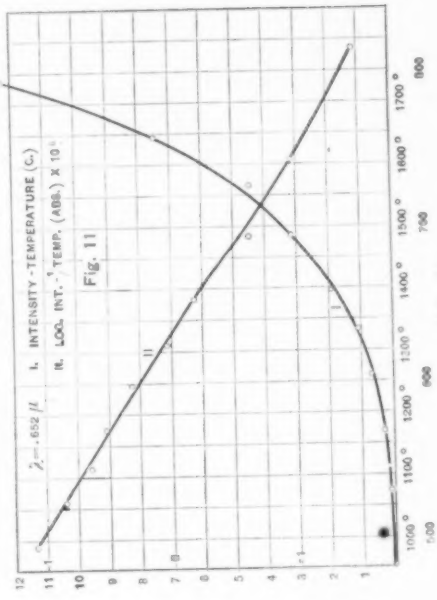

Fig. 11.

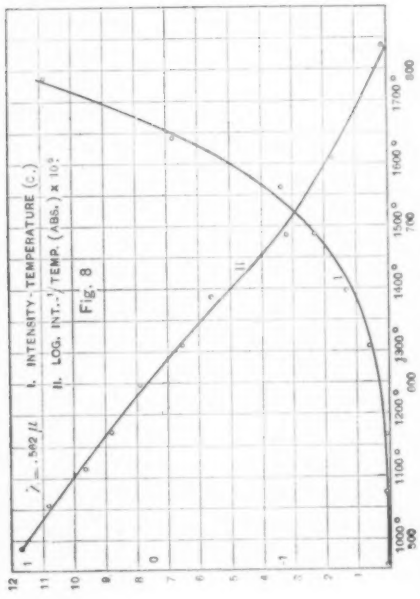

Fig. 8.

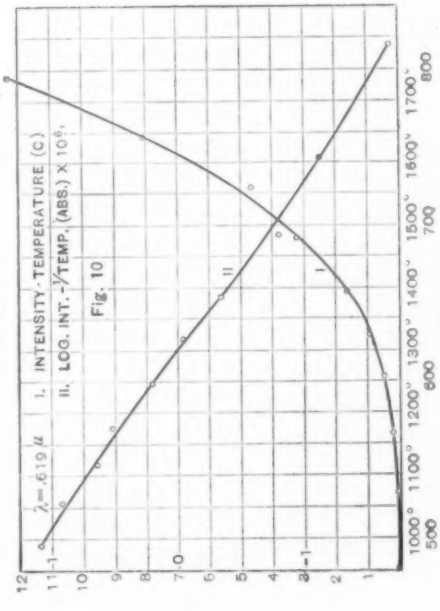

Fig. 10.

only a shifting of the origin of temperatures. From W. Wien's [1] equations for black bodies,

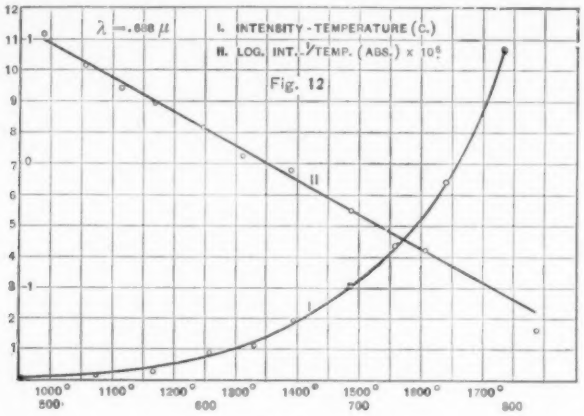

Fig. 12.

$$E = C_1 \lambda^{-5} e^{-\frac{C_2}{T\lambda}}$$

it will be seen if it be transformed into a logarithmic equation,

$$\log E = \log C_1 - 5 \log \lambda - \frac{C_2}{T\lambda} \log e,$$

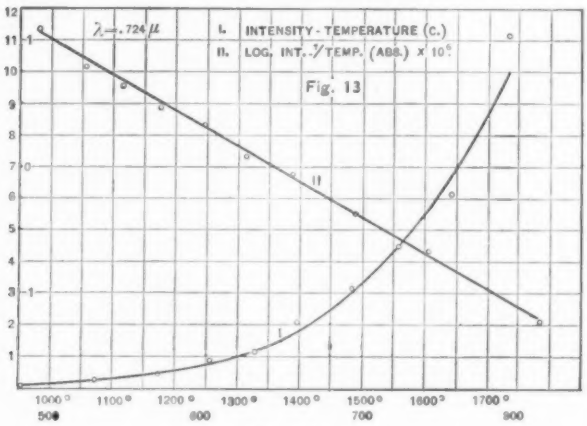

Fig. 13.

that if logarithms of intensity and reciprocals of absolute temperature be plotted as coördinates for a given value of λ, that a straight

[1] W. Wien, Wied. Ann., 58, 1896, p. 662, etc.

line would be the result; and that if intensity and temperature were plotted an exponential curve would result. Paschen's[1] modifications of Wien's equation,

$$E = C_1 \lambda^{-a} e^{-\frac{C_2}{T\lambda}}$$

in which the exponent of λ is changed to the more general form, shows the same general form of curves. Lummer and Pringsheim[2] in testing Wien's equation, arrive at the conclusion that C_1 and C_2 have a progressive variation such as to make the curves plotted

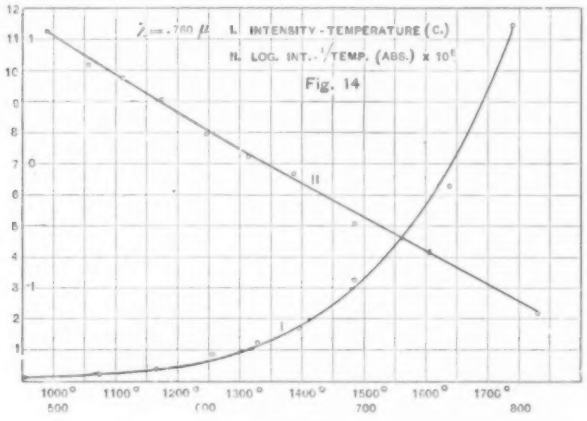

Fig. 14.

with log I, and reciprocals of absolute temperatures, convex to the $1/T$ axis. It will be seen from the "isochromatic curves" that for the longer wave-lengths at the temperatures of these experiments the radiation seems to follow very closely the laws of radiation for "black" bodies; and that for the higher temperatures used, the intensity of all the rays followed the same laws, nearly, but that for light of a refrangibility greater than $\lambda = .619\mu$, the deviation from this becomes greater and greater, reaching a maximum at about $\lambda = .515\mu$ and then decreases again.

From these curves were obtained the data from which curves were drawn using intensities and wave-lengths as coördinates, which show the relative increase in intensity of the various wave-lengths as the potential, and consequently, the temperature, was increased.

[1] F. Paschen, Astro. Phys. Jour., No. 10, June, 1899, p. 40.

[2] Lummer & Pringsheim, Verh. Deutsch. Phys. Ges., I., 1, 1900.

These curves show first that the intensity is a maximum, as compared with acetylene, in the longest wave-lengths. With the higher voltages the increase in intensity is more rapid toward the shorter wave-lengths and the ratio of increase is such that the maximum

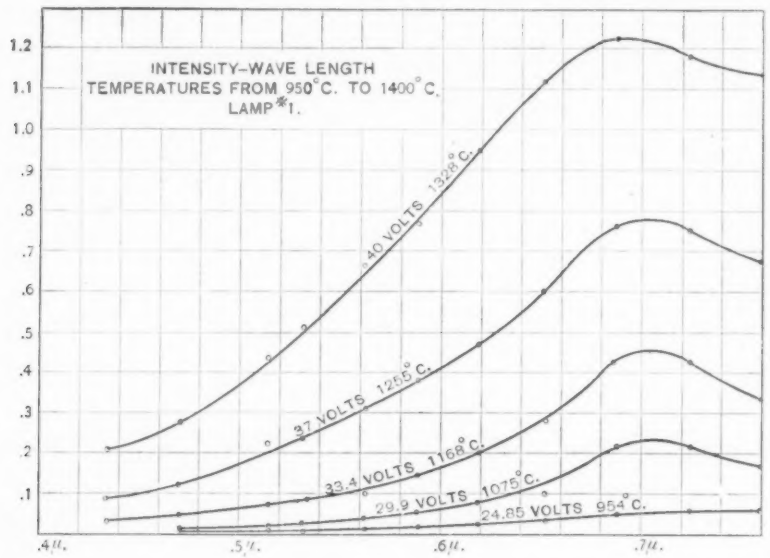

Fig. 15.

shifts toward the violet. With yet higher voltages the longer wave-lengths near the limits of the visible spectrum increase more in their intensity than near the maximum intensity, and this part of the curve also becomes concave to the axis of wave-lengths. In order to show the variation of intensity with temperature the curves for wave-length and temperature have been plotted on the same sheet. (See Figs. 15 and 16.)

In Table II. are given the data complete for each test. *Pd* refers to the difference of potential between the terminals of the test lamp. *I* refers to the current, *W* refers to the watts, and *R* gives the resistance corresponding for the lamp. *P* denotes the pressure of the gas burned in the comparison lamp in centimeters of water; O_c and O_A give the zero reading on the screw heads regulating the width of the slit openings, *C* referring to the test carbon source, and *A* referring to the acetylene comparison source. For opening slits the numbers on the screw heads increase so that on reaching the

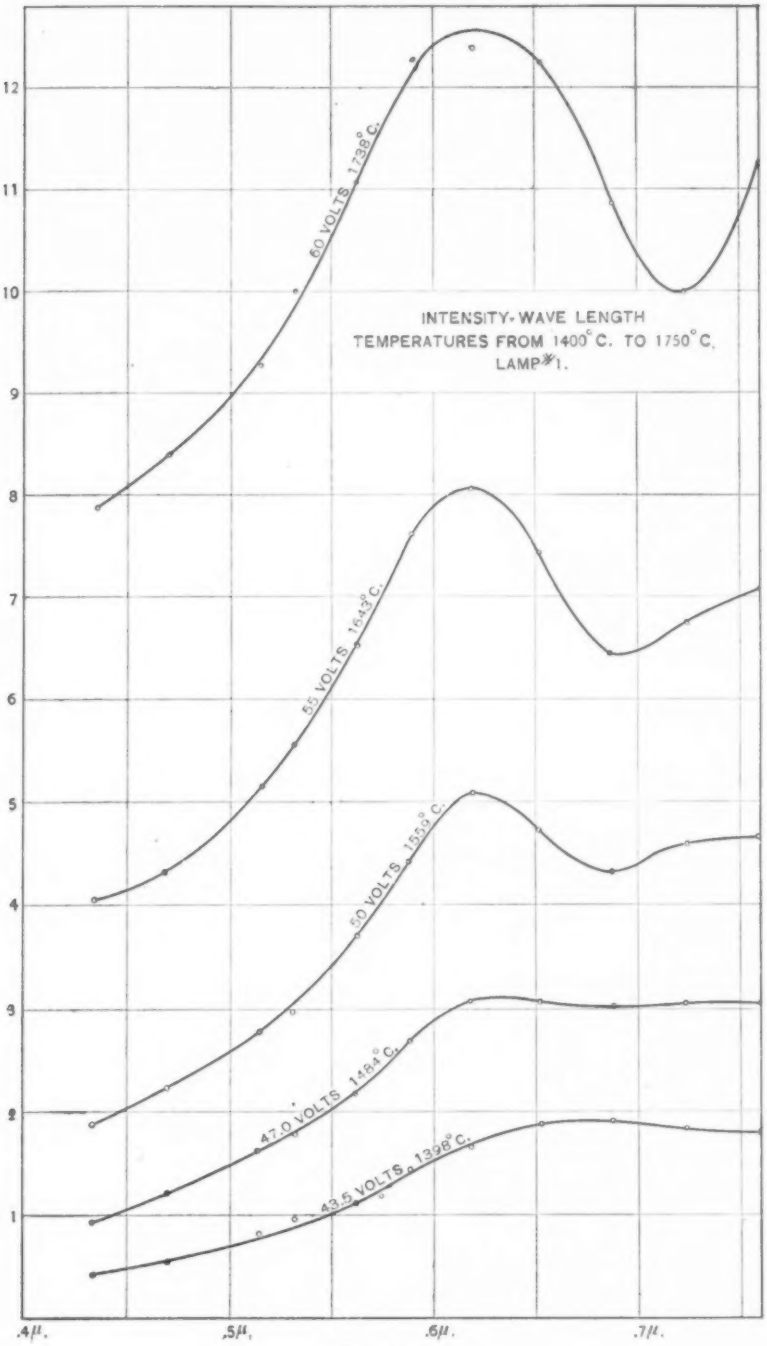
INTENSITY-WAVE LENGTH
TEMPERATURES FROM 1400° C. TO 1750° C.
LAMP #1.
60 VOLTS 1738° C.
55 VOLTS 1643° C.
50 VOLTS 1559° C.
47.0 VOLTS 1484° C.
43.5 VOLTS 1398° C.
12
11
10
9
8
7
6
5
4
3
2
1
.4μ.
.5μ.
.6μ.
.7μ.

Fig. 16.

TABLE II.

$Pd = 24.85$; $I = .456$; $W = 11.36$; $R = 54.5$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 79$.

C Slit Open 1 mm.										
λ = .760	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
88.00	84.6	83.9	82.2	81.3	80.3	80.3	80.1	79.3	79.9	
89.60	85.6	84.1	82.8	81.6	80.6	80.3	79.9	80.0	79.8	
87.60	87.4	84.2	82.2	81.0	81.0	80.5	80.0	80.0	79.3	
90.00	85.2	84.7	82.5	81.2	80.7	80.6	80.0	79.9	79.7	
88.00	86.1	84.4	82.9	81.2	81.0	80.2	80.3	79.8	79.7	
86.60	87.0	84.0	82.3	81.2	81.3	80.6	80.1	80.1	79.6	
85.4	86.6									
88.1	86.9									
89.0	87.4									
87.2	87.2									
87.95	86.4	84.22	82.48	81.25	80.82	80.42	80.07	79.85	79.67	
A^1 open										
8.95	7.40	5.22	3.48	2.25	1.82	1.42	1.07	.85	.67	
Int.										
.06	.059	.047	.034	.02	.015	.014	.009	.008	.007	
Log. I.										
-2.7782	-2.7709	-2.6721	-2.532	-2.301	-2.1761	-2.1461	-3.9542	-3.9031	-3.8451	

$Pd = 29.9$; $I = .575$; $W = 17.18$; $R = 52.0$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 79$.

C Slit Open 1 mm.									
λ = .760	.724	.688	.652	.619	.589	.562	.532	.515	.470
107.0	104.8	101.8	89.8	89.0	83.8	83.0	82.2	81.0	80.0
108.3	105.6	106.0	97.6	87.8	85.5	83.4	81.5	80.7	80.0
103.8	106.1	99.8	89.8	85.2	84.0	83.0	81.7	80.5	80.0
106.3	105.0	101.6	91.7	88.0	85.2	83.1	81.0	80.6	80.1
106.1	105.2	96.8	90.8	85.1	85.0	82.4	81.8	80.5	79.9
108.0	107.8	104.0	91.8	86.9	84.0	82.8	81.6	80.9	79.8
106.7	105.0								
104.0	107.7								
104.0	105.5								
102.6	106.6								
105.68	105.93	101.67	90.92	87.0	84.58	82.95	81.63	80.7	79.97
A open									
26.68	26.93	22.67	11.92	8.0	5.58	3.95	2.63	1.7	.97
Int.									
.194	.219	.201	.11	.076	.053	.038	.023	.015	.009
Log. I.									
−1.2878	−1.3414	−1.3032	−1.0414	−2.88	−2.72	−2.579	−2.352	−2.17	−3.9542

[1] "C slit open" refers to the collimator slit opening of test lamp. "A open" refers to the number of scale divisions of opening of the standard. 100 divisions = 1 turn = 1 mm.

$Pd = 33.4$; $I = .668$; $W = 22.31$; $R = 50.0$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 79.0$.

C Slit Open .5 mm.		C Slit Open 1 mm.								
$\lambda = .760$	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
100.0	104.2	118.8	106.1	96.0	90.0	88.2	86.9	84.6	82.4	81.0
96.5	102.6	117.0	105.0	96.3	92.5	88.3	85.9	85.0	82.3	81.0
100.0	103.1	115.3	104.3	96.3	90.0	87.2	86.0	84.3	82.6	81.0
100.6	100.1	117.2	105.3	96.0	91.7	87.5	87.0	84.8	82.2	80.8
97.0	103.9	117.6	103.8	96.6	93.1	87.3	85.4	85.2	82.0	81.0
96.0	99.3	115.2	106.0	95.8	91.8	87.6	86.8	84.3	81.9	81.2
96.3	100.3	117.4	105.1	95.6	91.0	87.0				
96.9	101.0	118.1	106.0	96.1	92.0	88.0				
94.2	101.3	117.5	104.8	97.1	89.8	88.2				
97.0	100.5	118.0	104.7	97.2	92.2	87.3				
97.45	101.68	117.21	105.11	96.3	91.41	87.66	86.32	84.7	82.23	81.0
A open										
18.45	22.68	38.21	26.11	17.3	12.41	8.66	7.32	5.7	3.23	2.0
Int. =										
.328	.428	.343	.247	.164	.12	.082	.065	.051	.032	.017
Log. I =										
−1.516	−1.631	−1.535	−1.392	−1.22	−1.07	−2.91	−2.81	−2.71	−2.51	−2.218

$Pd = 37.0$; $I = .763$; $W = 28.24$; $R = 48.49$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 79.0$.

C Slit Open .5 mm.								C Slit Open 1 mm.		
$\lambda = .760$	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
126.8	126.0	123.7	114.8	102.4	100.2	95.8	92.9	101.6	90.6	89.2
124.5	120.0	124.1	112.2	102.5	98.1	97.0	91.3	102.0	91.8	91.9
119.1	126.0	125.6	112.0	105.0	100.0	96.0	91.8	100.9	90.0	87.8
122.0	123.7	126.0	110.0	104.7	99.0	96.4	92.0	101.9	94.0	90.0
122.3	118.0	124.6	115.0	102.0	98.1	94.8	91.9	101.3	91.8	91.0
119.0	121.5	120.4	111.2	103.0	98.9	95.6	91.4	102.1	92.6	89.5
116.0	127.0	123.1	113.1	102.1	100.3	96.0	92.4	101.5	91.2	89.8
119.0	122.6	120.8	116.7	103.2	97.0	96.0	93.8	102.2	91.5	89.0
115.8	124.0	124.7	113.2	101.2	99.0	95.7	93.1	100.0	93.6	90.6
117.2	123.0	119.8	113.3	101.8	97.2	95.2	91.9	101.7	92.0	89.0
120.17	123.18	123.28	113.15	102.79	98.78	95.85	92.25	101.52	91.91	89.78
A open										
41.17	44.18	44.28	34.15	23.79	19.78	16.85	13.25	22.52	12.91	10.78
Int. =										
.802	.874	.866	.661	.461	.386	.328	.252	.203	.119	.095
Log. I =										
−1.904	−1.942	−1.938	−1.820	−1.664	−1.587	−1.51	−1.40	−1.308	−1.75	−2.975

$Pd = 39.9$; $I = .845$; $W = 33.72$; $R = 47.22$; $P = 7.35$ cm.; $O_c = 95.8$; $O_A = 79.0$.

	C Slit Open .25 mm.				C Slit Open .5 mm.				C Slit Open 1 mm.	
$\lambda = .760$	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
109.3	107.5	105.8	107.5	100.0	117.2	107.3	105.6	100.6	108.0	100.0
109 3	108.0	109.0	106.5	104.0	117.6	106.4	103.2	100.7	107.4	98.2
106.9	109.0	106.0	106.0	103.2	117.4	105.3	107.6	98.7	110.0	102.7
109.0	106.5	107.8	107.6	103.2	113.8	107.4	102.1	100.0	112.5	96.5
106.0	107.0	106.8	105.0	103.1	113.9	108.0	101.8	101.6	113.0	96.5
109.2	108.0	111.4	104.0	104.4	118.2	109.8	103.8	101.5	111.0	96.8
108.5	110.0	104.8	105.6	101.6	117.0	108.8	103.8	100.2	108.3	99.3
108.6	108.8	106.1	104.1	100.8	119.5	106.9	103.5	98.5	109.8	101.8
109.0	110.0	109.8	105.7	102.8	114.2	106.4	104.8	100.0	108.1	98.8
105.0	109.9	106.0	103.2	104.2	119.1	107.9	104.6	103.0	109.1	98.2
107.98	108.52	107.35	105.53	102.73	116.49	107.42	103.78	100.48	109.72	98.88
A open										
28.97	29.52	28.35	26.53	23.78	37.49	28.42	24.78	21.48	30.72	19.88
Int. =										
1.161	1.193	1.138	1.07	.945	.756	.56	.482	.413	.286	.182
Log. I =										
.065	.077	.056	.029	−1.975	−1.879	−1.74	−1.683	−1.616	−1.456	−1.259

$Pd = 43.4$; $I = .943$; $W = 40.93$; $R = 46.2$; $P = 7.35$ cm.; $O_c = 95.8$; $O_A = 79$.

	C Slit Open .25 mm.							.5 mm.	1 mm.	
$\lambda = .760$	.724	688	.652	.619	.589	.562	.532	.515	.470	.434
119.7	127.0	129.8	123.8	120.0	114.0	111.8	105.3	101.7	106.6	123.7
118.1	129.6	126.9	129.0	121.3	118.5	110.6	103.0	100.1	107.6	127.7
124.0	125.5	126.1	125.6	121.0	113.0	109.5	104.4	102.0	108.5	121.2
123.4	125.6	131.1	125.8	119.0	113.0	109.3	102.8	100.5	108.0	117.5
123.8	129.0	125.7	124.7	122.8	121.0	111.0	106.5	101.0	108.6	130.0
117.2	130.5	124.5	121.1	117.2	116.0	112.8	103.2	100.8	105.7	132.0
121.1	125.6	128.0	128.1	117.5	115.9	113.0	105.5	102.5	106.7	127.0
118.0	128.0	127.4	125.9	118.0	115.0	110.8	105.3	102.0	108.3	128.0
117.8	124.5	124.5	125.2	119.6	118.5	109.8	107.8	99.1	108.5	130.5
121.8	125.0	126.0	125.6	121.0	114.5	111.0	104.6	98.8	106.4	122.5
120.49	127.03	127.0	125.48	119.74	115.94	110.96	104.84	101.65	107.31	126.0
A open										
41.49	48.03	48.0	46.48	40.74	36.94	31.96	25.84	22.65	28.31	47.0
Int. =										
1.77	2.01	1.96	1.99	1.65	1.49	1.28	1.03	.91	.55	.459
Log. I =										
.248	.3032	.295	.299	.219	.173	.108	.01	−1.96	−1.747	−1.662

$Pd = 47.0$; $I = 1.055$; $W = 49.59$; $R = 44.55$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 78.2$.

C Slit Open .2 mm.							C Slit Open .25 mm.			
λ = .760	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
134.0	135.6	135.0	144.6	141.0	131.0	119.6	121.0	116.7	107.1	99.7
133.2	137.2	136.0	142.8	144.5	127.9	121.7	121.0	118.0	110.1	101.1
136.4	135.3	137.1	140.0	137.0	131.8	122.0	121.4	118.2	112.2	102.7
136.2	136.0	137.2	140.0	140.1	135.2	118.8	124.0	119.4	111.1	102.2
134.4	136.6	137.8	142.7	138.5	130.0	122.1	122.2	119.5	107.2	101.0
134.0	136.2	136.0	138.0	141.0	131.5	118.6	125.2	116.0	111.0	104.5
133.9	134.6	138.5	144.0	144.2	133.0	119.7	123.2	119.0	111.0	99.5
133.1	130.8	138.4	142.2	137.8	129.0	119.2	123.0	117.8	110.2	101.0
135.5	134.6	135.5	141.9	138.5	133.8	119.3	123.0	119.0	112.0	98.5
136.3	137.2	136.3	140.2	142.0	130.3	122.2	122.2	119.2	109.0	100.5
134.7	135.41	136.78	141.64	140.46	131.35	120.32	122.62	118.28	110.09	101.07
A open										
56.4	57.21	58.58	63.44	62.26	53.15	42.12	44.42	40.08	31.89	22.87
Int. =										
3.20	3.07	3.04	3.295	3.265	2.77	2.16	1.79	1.64	1.29	.91
Log. *I* =										
.505	.487	.483	.518	.514	.443	.335	.253	.214	.111	—1.957

$Pd = 50.0$; $I = 1.155$; $W = 57.75$; $R = 43.29$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 78.2$.

C slit open .2 mm.			C slit open .10 mm.							.25 mm.
λ = .760	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
157.8	157.8	156.0	123.6	122.8	118.0	109.0	107.0	107.0	102.3	111.2
150.5	157.2	159.7	119.5	124.0	120.5	109.9	107.5	105.2	98.0	115.8
152.0	156.8	156.8	121.8	124.5	116.1	109.1	106.9	106.5	103.0	115.0
161.8	159.8	161.0	120.2	120.9	120.6	111.2	108.0	104.6	100.0	113.8
157.4	157.0	161.8	120.0	120.5	117.0	112.7	106.9	105.9	99.5	109.0
153.4	159.0	158.6	123.3	125.0	119.1	111.5	107.9	105.3	102.6	118.6
155.0	156.3	158.5	122.1	120.2	122.0	110.3	107.2	105.0	101.0	112.0
154.2	158.0	156.8	122.6	121.2	115.0	112.8	109.0	105.0	100.0	116.0
154.8	159.0	159.4	122.1	123.0	115.2	110.0	109.3	105.9	99.9	111.0
153.0	155.7	157.7	123.0	123.6	116.7	111.8	108.0	104.4	99.0	108.0
154.99	157.66	158.63	121.82	122.57	118.02	110.83	107.77	105.48	100.53	113.04
A open										
76.79	79.46	80.43	43.62	44.37	39.82	32.63	29.57	27.28	22.33	34.84
Int. =										
4.67	4.50	4.33	4.46	4.64	4.18	3.34	2.98	2.78	2.22	1.42
Log. *I* =										
.669	.653	.637	.649	.665	.621	.524	.474	.444	.346	.153

$Pd = 55.0$; $I = 1.31$; $W = 72.05$; $R = 41.98$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 78.2$

C Slit Open .1 mm.		.075 mm.	C Slit Open .1 mm.			.075 mm	C Slit Open .1 mm.			
λ = .760	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
132.3	136.0	122.8	152.4	155.0	154.8	129.2	134.5	133.3	123.1	118.5
133.8	136.0	127.5	148.2	152.5	150.1	128.3	135.0	129.1	118.9	114.8
131.0	137.2	122.4	149.5	156.8	146.8	126.7	131.8	132.0	120.0	116.5
134.8	137.1	122.8	151.5	151.2	151.0	128.0	131.0	134.2	116.0	116.2
131.4	132.6	126.8	146.2	154.8	146.0	123.0	135.8	127.0	120.6	114.8
132.6	134.9	124.5	153.8	155.2	148.8	123.8	132.2	130.5	116.9	113.0
129.4	132.0	127.8	152.2	152.1	149.7	123.6	135.0	138.0	120.3	116.5
129.5	133.8	126.0	145.1	151.8	150.0	124.2	131.4	133.0	124.6	115.1
133.3	134.2	125.2	147.5	154.8	149.1	129.0	132.6	129.8	124.0	118.8
133.0	137.2	124.1	149.2	152.9	146.3	126.3	136.4	133.1	123.2	116.7
132.11	135.1	124.99	149.56	153.71	149.26	126.21	133.57	131.0	120.76	116.09
A open										
53.91	56.9	46.89	71.36	75.51	71.06	48.11	55.37	52.8	42.56	37.89
Int. =										
6.24	6.12	6.42	7.48	8.06	7.68	6.72	5.73	5.53	4.36	4.05
Log. *I* =										
.795	.787	.808	.874	.906	.885	.827	.758	.743	.639	.607

$Pd = 60.0$; $I = 1.48$; $W = 88.80$; $R = 40.54$; $P = 7.35$; $O_C = 95.8$; $O_A = 7.80$.

C Slit Open .08 mm.				.619	.589	.562	.532	.515	.470	.434
λ = .760	.724	.688	.652							
146.0	158.1	155.0	170.6	173.6	163.5	158.8	156.6	144.0	137.5	133.2
145.1	155.6	156.2	167.8	172.5	161.4	160.8	152.0	145.2	141.0	135.2
148.6	152.2	156.4	164.3	175.0	167.0	160.4	155.9	146.9	142.2	134.4
148.8	158.2	154.0	172.8	175.2	161.2	160.4	149.4	144.1	140.2	134.8
151.9	156.6	163.2	171.5	166.2	163.2	158.6	154.8	145.1	140.0	133.6
152.0	156.0	161.2	165.3	170.6	164.1	159.4	149.4	147.2	140.6	132.4
149.6	154.4	162.2	172.9	161.0	162.8	157.5	157.1	140.6	142.0	135.7
152.5	153.1	155.6	170.5	161.5	168.0	158.6	150.3	144.2	140.2	130.0
147.8	156.7	155.1	169.4	180.9	167.2	160.0	152.4	148.0	137.0	134.4
146.3	152.8	161.8	166.7	168.0	160.0	161.1	152.6	146.1	139.1	132.0
148.86	155.37	158.07	169.18	170.45	163.84	159.56	152.45	145.14	139.98	133.57
A open										
70.86	77.37	80.07	91.18	92.45	85.84	81.56	74.45	67.14	61.98	55.57
Int. =										
11.42	11.18	10.83	12.25	12.38	12.26	10.90	10.00	9.25	8.40	7.86
Log. *I* =										
1.050	1.048	1.035	1.088	1.094	1.089	1.037	1.000	.966	.924	.895

the zero of the scale 1 was prefixed to the reading for the sake of clearness, there being 100 divisions on the screw head and one complete turn equaling an increase in opening of the slit of one millimeter. "*A* open" gives the number of divisions of the comparison

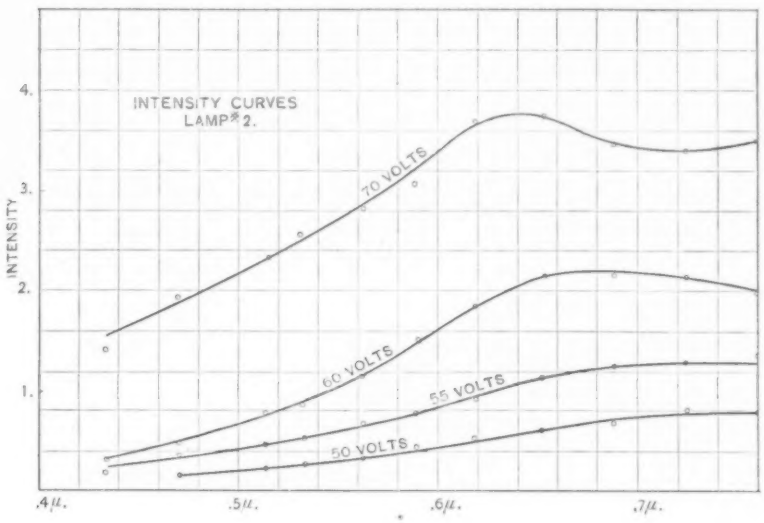

Fig. 17.

slit open to produce equality of illumination and the row marked "I n t" gives the ratio of the intensity of the carbon light radiation to the intensity of the acetylene for the given wave-length.

Gray and black carbon show marked differences in their efficiency, as has been shown by M. Evans [1] and confirmed by J. T. Bottomley [2] and J. C. Shedd,[3] and later by Dr. Nichols [4] in his study of the spectrum of the glow lamp. It was desired to find whether this change in the rate of change of luminosity was a characteristic of gray carbon alone, or whether it also was apparent in black carbon. A lamp was accordingly taken the filament of which had been carefully treated by coating with lampblack.[5] This lamp showed a

[1] Mr. M. Evans, Proc. Royal Soc., Vol. XL., Feb. 18, 1886, pp. 207–214.
[2] J. T. Bottomley, Phil. Trans., 1887, p. 429.
[3] J. C. Shedd, Thesis, Cornell University Library, 1892.
[4] Dr. E. L. Nichols, PHYS. REV., Vol. II., 1895, pp. 260–276.
[5] Same, p. 264.

much lower efficiency than lamp No. 1 with the gray filament. It will be noticed from the data given in Table III. that as the voltage increased the resistance also increased and that, therefore, it is impossible to apply Le Chatelier's results to determine the rise in temperature.

TABLE III.

V	I	W	C. P.	$\frac{W}{\text{C. P.}}$	R.
50	1.51	75.5	4.58	16.5	33.11
55	1.65	90.75	8.68	10.45	33.33
60	1.78	106.8	14.30	7.46	33.71
70	2.04	142.8	31.24	4.57	34.31

As will be seen from Table IV. and Fig. 17 the same characteristic form of curve, with maximum shifting to the small wavelengths as the voltage rose, was likewise found in the case of this lamp.

As a final check on the results obtained using the Lummer-Brodhun spectrophotometer, a Nichols spectrophotometer was used. This instrument is made up of a horizontal collimator at one end of which are placed two totally reflecting prisms, the sources being studied being placed on a line perpendicular to the axis of the tube. The amount of incident light is regulated by means of two adjustable horizontal slits which are governed by micrometer screws.

TABLE IV.

$Pd = 50.00$; $I = 1.51$; $W = 75.5$; $R = 33.11$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 78.0$.

1 mm.	C Slit Open .5 mm.									
$\lambda = .760$	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
165.0	117.1	111.1	106.4	103.4	98.8	95.0	92.0	89.3	85.8	
163.1	117.5	114.6	108.5	103.3	100.3	94.0	90.7	89.1	85.1	
160.0	118.2	111.2	108.2	102.2	99.2	93.2	91.6	88.1	84.1	
161.6	118.0	113.2	109.0	104.9	98.8	94.7	91.0	89.2	85.0	
164.1	117.8	111.3	108.9	103.2	100.0	93.0	91.1	89.0	85.0	
160.0	119.0	112.0	108.2	104.1	99.9	94.5	90.8	88.8	84.2	
162.3	117.93	112.24	108.2	103.52	99.5	94.07	91.2	88.92	84.88	
A open										
84.3	39.93	34.24	30.2	25.52	21.5	16.07	13.2	10.92	6.88	
tIn.=										
.76	.78	.655	.582	.499	.421	.312	.251	.201	.123	

$Pd = 55.0$; $I = 1.65$; $W = 90.75$; $K = 33.33$; $P = 7.35$ cm.; $O_c = 95.8$; $O_4 = 78.0$.

C Slit open .5 mm.	C Slit Open .25 mm.								1 mm.
λ=.760	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
143.3	136.8	106.6	108.0	100.0	97.6	93.6	91.1	89.8	87.2	97.1
139.1	134.6	111.5	109.1	100.2	97.2	94.0	92.0	90.0	87.6	96.0
144.4	140.3	111.8	103.6	100.3	96.8	94.0	90.6	90.0	87.0	98.7
143.0	138.6	108.5	106.2	101.0	97.2	95.4	91.3	88.4	86.2	95.2
141.5	141.0	107.0	107.7	102.0	96.0	95.4	92.6	89.3	87.8	94.8
143.5	143.0	105.0	106.3	101.5	98.5	92.2	91.9	89.4	86.2	97.2
	138.2	105.7	106.2	102.1	98.2	96.0	91.0	89.1	86.0	96.8
	141.0	108.6	102.8	100.8	98.3	94.0	93.0	89.7	85.8	96.2
	144.5	108.8	103.2	99.8	97.1	95.8	92.8	89.1	86.0	95.8
	140.0	107.9	106.5	101.3	97.8	95.2	91.0	89.4	86.1	98.0
142.47	139.8	108.14	105.96	100.9	97.47	94.56	91.73	89.42	86.59	96.58
A open										
64.47	61.8	30.14	27.96	22.9	19.47	16.56	13.73	11.42	8.59	18.58
Int. =										
1.35	1.27	1.22	1.12	.91	.77	.66	.53	.45	.35	.17

$Pd = 60.0$; $I = 1.78$; $W = 106.8$; $K = 33.71$; $P = 7.35$ cm.; $O_c = 95.8$; $O_4 = 78.0$.

C Slit Open .25 mm.									1 mm.
λ=.760	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
125.6	132.3	129.5	129.8	120.8	114.6	104.8	102.6	95.8	91.3	114.0
122.4	131.3	131.6	131.0	125.0	115.3	107.2	101.9	97.8	93.4	109.0
122.0	129.0	129.0	129.5	122.0	114.2	105.9	102.4	98.3	91.8	114.7
122.0	126.8	129.0	127.5	121.4	116.0	104.9	102.3	97.0	92.2	112.3
125.0	129.0	132.8	130.0	125.0	114.2	105.8	101.8	97.7	93.7	110.3
124.1	130.9	127.4	129.7	122.8	114.0	109.0	101.2	97.9	91.8	107.8
121.6	125.2	130.0								
124.7	126.5	129.0								
122.1	128.3	130.0								
124.2	126.0	131.2								
123.37	128.53	129.95	129.58	122.63	114.72	106.27	102.03	97.42	92.37	111.35
A open										
45.37	50.53	51.95	51.58	44.63	36.72	28.27	24.03	19.42	14.37	33.35
Int. =										
1.96	2.13	2.14	2.12	1.82	1.49	1.13	.96	.78	.58	.32

$Pd = 70.0$; $I = 2.04$; $W = 142.8$; $R = 34.31$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 78$.

C Slit Open .1 mm.										.5 mm.
λ = .760	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
108.1	110.8	110.0	113.1	113.2	108.1	105.7	102.8	102.0	97.1	145.2
111.5	112.3	114.2	113.3	115.0	107.8	103.6	102.4	100.3	96.0	151.2
111.0	112.5	113.8	115.5	111.0	110.0	106.2	104.0	101.5	98.0	140.0
108.8	110.0	113.7	116.9	114.3	105.4	107.2	100.7	99.1	95.6	144.8
111.0	112.2	112.2	113.7	113.3	106.5	105.8	104.2	102.4	97.5	149.5
110.7	109.9	111.3	116.2	113.3	108.8	105.7	104.8	100.2	98.0	143.7
110.18	111.28	112.53	114.76	113.36	107.43	105.7	103.15	100.92	97.03	145.73
A open										
32.18	33.28	34.53	36.76	35.35	29.43	27.07	25.15	22.92	19.03	67.73
Int. =										
3.49	3.42	3.45	3.74	3.68	3.07	2.81	2.54	2.31	1.92	1.39

The two beams of light impinge upon a metal grating placed with the lines horizontal, so that the spectrum produced is vertical. The examining telescope swings in a vertical plane, as does also the grating, for purposes of adjustment. The spectrum produced by this instrument is a distinct normal one of about ten degrees dispersion between the limits of the visible spectrum. The character of the spectrum afforded by this instrument and the conditions of working with it differ so widely from those of the Lummer-Brodhun spectrophotometer as to offer an admirable control of the general correctness of the measurements made with the latter. Runs upon the lamp with the gray filament were made at fifty volts and at sixty-two and one-half volts. The curves obtained show the same general form with the shifting of the maximum toward the shorter wave-lengths, thus confirming the previous work and showing that the effect was a real one. No particular stress is laid on the readings for .76 μ or for .434 μ as to their real value but they do show the general trend of the curves. The data given in Table V. are for this test.

Table VI. gives the percentage, taken from the curves, for each wave-length, of the intensity at a given voltage over the value of the intensity of the same wave-length at the next lower voltage, for the lamp with the gray filament.

The results of the experiments here described are in accordance with the phenomenon observed by Dr. Nichols in his spectro-pho-

TABLE V.

$Pd = 50.0$; $I = 1.15$; $W = 57.5$; $R = 43.45$; $P = 7.35$ cm.; $O_C = 3.6$; $O_A = 88.5$.

	A Open 1 Turn.									
$\lambda = .760$	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
40.4	43.8	43.0	52.5	59.2	66.4	61.5	67.2	68.5		
46.3	44.8	42.5	53.6	55.2	60.5	67.8	66.4	73.0		
	46.4	42.2	50.8	57.5	61.6	63.8	70.5	72.5		
	44.4	41.3	51.8	55.8	62.6	66.6	69.6	71.1		
	43.4	41.2	51.9	55.7	64.2	67.1	69.5	68.0		
43.35	44.56	42.4	52.12	56.68	63.06	65.36	68.64	70.62		
C open										
39.75	40.96	38.46	48.52	53.08	59.46	61.76	65.04	67.02		
Int. =										
2.52	2.44	2.60	2.06	1.88	1.71	1.62	1.54	1.49		

$Pd = 62.5$; $I = 1.56$; $W = 97.5$; $R = 40.5$; $P = 7.35$ cm.; $O_C = 3.4$; $O_A = 88.5$.

2 Turns.	A Open 1 Turn.									
$\lambda = .760$	.724	.688	.652	.619	.589	.562	.532	.515	.470	.434
33.0	21.2	22.1	20.9	20.8	24.6	24.8	27.7	27.3	33.1	63.0
31.5	20.8	23.4	20.8	21.1	22.6	26.1	29.8	29.5	31.3	66.2
31.4	21.4	21.9	21.2	20.9	23.1	25.5	25.6	29.2	33.5	66.8
31.9	20.4	20.7	20.8	21.1	23.8	25.3	25.5	27.3	29.3	63.5
31.4	21.4	21.8	21.2	21.8	24.8	24.5	26.7	29.1	29.5	64.3
31.84	20.96	21.98	20.98	21.14	23.78	25.24	27.06	28.48	31.34	64.76
C open										
28.44	17.56	18.58	17.58	17.74	20.38	22.84	23.66	25.08	27.94	61.3
Int. =										
7.03	5.69	5.38	5.68	5.64	4.91	4.38	4.23	4.00	3.58	3.2

TABLE VI.

Volts.	Wave-Lengths.										
	.434	.470	.515	.532	.562	.589	.619	.652	.688	.724	.760
24.85	—	—	—	—	—	—	—	—	—	—	—
29.9	—	167	244	267	362	353	343	358	436	369	285
33.4	—	372	367	345	287	270	251	225	199	196	198
37.0	274	260	283	287	282	263	235	210	178	176	198
40.0	241	227	213	212	209	207	202	186	161	159	170
43.5	212	207	182	174	174	181	182	169	156	156	158
47.0	218	214	208	204	196	192	182	163	158	166	169
50.0	188	184	171	170	169	164	165	155	142	150	153
55.0	215	194	186	182	176	172	159	157	148	148	152
60.0	195	196	181	177	170	160	156	165	169	148	160

tometric observations on incandescent rods, cited above. The observations at the higher temperatures at which it was possible to work, with some fair degree approximating that of the acetylene flame, show that the distribution of energy in the spectra of acetylene and of the carbon filaments at the same temperature is not the same, as has been thought to be the case. The isotherms for the gray carbon rod, figure 22 in the paper of Dr. Nichols, begin to show the same characteristics that are brought out in the present work at the higher temperatures, namely, that after passing a maximum, compared to acetylene, in the orange a minimum is reached in the red, the comparative intensity again increasing toward the infra red. By a reference to the intensity-temperature curves it will be seen that crossing of the isochroms predicted at higher temperatures, in Dr. Nichols's paper has really taken place, the curve for wave-length .562 μ cutting those of .688 μ and .724 μ, while the curve for wave-length .589 μ cuts every one of wave-length greater than .562 μ excepting that for wave-length .619 μ which it would likely intersect at a temperature not much higher.

It is also seen by a comparison of the isotherms for gray carbon and for the black filament that the same characteristics are brought out and this phenomenon of selective radiation is one not due to the nature of the carbon surface.

I desire, in concluding, to express my gratitude to Dr. Nichols, at whose suggestion this investigation was taken up, for many valuable suggestions and his inspiring interest in the work.

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NOTE ON ELECTROMETERS.

By William Duane.

IN most symmetrical electrometers, such as the quadrant, the needle or movable conductor is made of different material from that of the fixed conductors. It is important in such cases to determine the effect, if there is one, of the electromotive force existing between two metals in contact with each other, or more strictly speaking of the difference in potential between two points in the air just outside the two metals in contact respectively. In most, and so far as the author is aware in all of the discussions and explanations of such electrometers these electromotive forces are neglected, whereas he has found both theoretically and experimentally that the Volta electromotive force under certain very common experimental conditions may introduce a large error into the measurement of a potential difference. Further he has found that, if the needle is suspended on a metal wire through which it is charged, and if the instrument is used idiostatically, the quadrant electrometer can be used to measure the Volta electromotive force with great accuracy.

To fix our ideas in regard to the Volta electromotive force suppose that V_a is the potential of a conductor A and V_b that of another conductor B. V_a and V_b are not in general the potentials in the air just outside the conductors, for owing to impressed electromotive forces in the transition layer on the surface of a conductor its potential is kept above or below that of the air in its immediate neighborhood.

Let φ_a and φ_b be the rises of potential (to be taken negative, if the potential falls) in passing from the conductors A and B respectively to the air just outside them. Then the potentials just outside the transition layers on the surfaces of A and B are $V_a + \varphi_a$ and $V_b + \varphi_b$ respectively. Suppose that the two conductors are placed in contact with each other. There is an im-

pressed electromotive force in their surface of contact, which produces a difference of potential between them unless they are of the same material or at their neutral temperature. Call this difference of potential φ_{ab} to be taken positive if B is at a higher potential than A. Imagine a closed line drawn partly in the two conductors and partly in the air outside the two conductors. In following along this line from a point just outside of A through A then B, and then through the air back to the starting point, the potential falls by the amount φ_a in passing the transition layer of A, rises by the amount φ_{ab} in passing from A to B, and again rises by the amount φ_b in passing from B back to the air just outside it. Hence the potential must fall by the amount $\varphi_b - \varphi_a + \varphi_{ab}$ along the portion of the line drawn in the air from B to A. This fall of potential is the Volta difference of potential.

At present we will make no assumption as to the relative magnitude of φ_a, φ_b, and φ_{ab}, *i. e.*, as to whether the seat of the Volta effect is the air surfaces of the conductors or their mutual contact surface. It is sufficient to state that we know from experiment that the potential difference $\varphi_b - \varphi_a + \varphi_{ab}$ is in general a large fraction of a volt, and may under certain circumstances be larger than one volt.

To return to the quadrant electrometer, suppose that V_1 and V_2 are the potentials of the two pairs of quadrants respectively, and that V_n is the potential of the needle. If the instrument is adjusted so as to be perfectly symmetrical the formula usually quoted connecting the deflection θ with the potentials is

$$\theta = k(V_1 - V_2)[V_n - \tfrac{1}{2}(V_1 + V_2)], \qquad (1)$$

where k is a constant for small deflections. In deducing this formula any electromotive forces and differences of potential that may exist at the surfaces of the various conductors are neglected.

It is evident, however, that the potential, and therefore the electric force at points inside the space enclosed by the quadrants and outside the needle, depends upon the potentials at points in the air just outside of the various conductors and not on the potentials of the conductors themselves. Hence the mechanical forces of attraction and repulsion will depend upon the values of $V_1 + \varphi_1$,

$V_2 + \varphi_2$, and $V_n + \varphi_n$ and not, of V_1, V_2 and V_n alone, and the former should be substituted for the latter in formula (1). Hence

$$\theta = k(V_1 - V_2 + \varphi_1 - \varphi_2)[V_n + \varphi_n - \tfrac{1}{2}(V_1 + V_2 + \varphi_1 + \varphi_2)]. \quad (2)$$

If the electrometer is used heterostatically and the needle is charged to so high a potential that any changes in V_1 and V_2 that may occur are negligible in comparison with it, the quantity in square brackets is practically constant, and equation (2) becomes

$$\theta = K(V_1 - V_2 + \varphi_1 - \varphi_2). \quad (3)$$

Further, if the quadrants are all of the same material, and their surfaces in the same condition, $\varphi_1 = \varphi_2$, and

$$\theta = K(V_1 - V_2) \quad (4)$$

which is independent of the φ's.

Even if the pairs of quadrants were of different materials or their surfaces in different conditions, the Volta differences of potential would have no effect, for in order to measure a difference of potential we first connect the two pairs of quadrants together so that $V_1 - V_2 = \varphi_{21}$, and the deflection then is

$$\theta_0 = K(\varphi_1 - \varphi_2 + \varphi_{21}) \quad (5)$$

which is the practical zero. We then join wires that are of the same material to the quadrants and to the two points to be investigated, and obtain the deflection

$$\theta_1 = K(E + \varphi_{21} + \varphi_1 - \varphi_2). \quad (6)$$

Since

$$V_1 - V_2 = E + \varphi_{21}$$

where E is the desired difference of potential.

The observed deflection is

$$\theta_1 - \theta_0 = KE \quad (7)$$

and is proportional to the difference of potential E.

Hence we conclude that if the electrometer is used heterostatically, the contact potential differences have no effect and need not be corrected for.

If, however, the instrument is used idiostatically the Volta difference of potential may produce a large error. Suppose the needle is connected with the pair of quadrants (1). Usually the needle connection is made through platinum wires that dip into a concentrated solution of sulphuric acid, and if the electrodes are not exactly the same the electromotive forces at their surfaces will not exactly balance each other and there will be a resulting difference of potential produced by the electrolyte. We will assume, however, that there is no such electromotive force in the needle circuit, or better still that the connection with the needle is made entirely through metallic conductors. Under these circumstances the potential of the needle is $V_n = N_1 + \varphi_{1n}$.

Assuming the quadrants to be of the same material and, therefore, $\varphi_1 = \varphi_2$, the formula (2) becomes

$$\theta = \frac{k}{2}(V_1 - V_2)[V_1 - V_2 + 2(\varphi_n + \varphi_{1n} - \varphi_1)]. \qquad (8)$$

The expression in parenthesis $\varphi_n + \varphi_{1n} - \varphi_1$ is the Volta difference of potential between the needle and the quadrants. It appears that the deflection θ is not strictly proportional to the square of the difference of potential as is usually stated, and that if the sign of the potential difference be reversed, the deflection will change in magnitude. These conclusions can be easily tested experimentally as described below. Further it is evident that if the Volta electromotive force is neglected, and the simple formula

$$\theta = \frac{k}{2}(V_1 - V_2)^2 \qquad (9)$$

used, a large error may be made in the measurement. For example, suppose we are measuring the constant k of the instrument by means of an electromotive force of 20 volts, and that the Volta electromotive force is .5 volt (it often is larger than this); then the value of k as calculated from (9) will differ from its true value as calculated from (8) by 5 per cent.

The change in the magnitude of the deflection on reversing the sign of the potential difference $V_1 - V_2$ is not due to a lack of symmetry in the adjustment of the instrument, for the deflection is on

the same side of the zero before and after the reversal. The only way to change the sign of the deflection is to join the needle to the other pair of quadrants, and when this is done we get a similar change in the magnitude of the deflection on reversing the potential difference, although in case of non-symmetry the actual magnitudes of the deflection may be much greater or less than they were before. It will be proved below that formula (8) holds true whether the instrument is exactly symmetrical or not.

The above theory was tested experimentally as follows. The bifilar suspension of an ordinary quadrant electrometer was taken out and a fine phosphor-bronze wire, through which the needle could be charged, substituted for it. A storage battery furnished a constant electromotive force of 36 volts. The apparatus was arranged according to the usual idiostatic method of measurement. It appeared that the maximum deflection always occurred on charging the quadrants connected with the needle positively. Calling θ_1 and θ_2 the maximum and minimum deflections respectively, the following numbers represent the averages of a dozen readings,

$$\theta_1 = 27.56 \text{ cm.} \quad \theta_2 = 27.06 \text{ cm.}$$

giving a difference in deflection of

$$\theta_1 - \theta_2 = .50 \text{ cm.}$$

It is well known that the Volta effect depends to a considerable extent upon the condition of the air surfaces of the metals, *i. e.*, whether they have been recently cleaned or not, etc. To test whether the difference in deflection would be altered in the same manner the needle was taken out, scraped with emery paper and replaced again. Owing to the unavoidable bending of the needle we would not expect to get the same deflection as before. Readings similar to the above gave

$$\theta_1 = 25.32 \text{ cm.} \quad \theta_2 = 22.75 \text{ cm.} \quad \theta_1 - \theta_2 = 2.57 \text{ cm.}$$

The actual deflections are slightly smaller but their difference has been increased to over five times the former difference, indicating a corresponding increase in the Volta effect. The needle was as usual

made of aluminium, and this increase in the Volta effect caused by cleaning the surface of aluminium is well known.

An estimate of the magnitude of the Volta effect can be obtained as follows: Putting $V_1 - V_2 = E$ the electromotive force of the battery, formula (8) becomes

$$\theta_1 = \frac{k}{2} E[E + 2\Phi]$$

where $\Phi = \varphi_n + \varphi_{1n} - \varphi_1$ is the Volta difference of potential. Reversing the electromotive force, $V_1 - V_2 = -E$, and

$$\theta_2 = \frac{k}{2} E[E - 2\Phi].$$

By adding, subtracting and elimininating k we get

$$\Phi = \frac{E(\theta_1 - \theta_2)}{2(\theta_1 + \theta_2)} \qquad (10)$$

The quadrants of the electrometer were of brass, and the above readings substituted in formula (10) give for this particular aluminium needle, and these particular brass quadrants $\Phi = .165$ volt before cleaning and $\Phi = .962$ volt after cleaning the needle.

In order to prove that the want of symmetry in the adjustment of the electrometer is not the cause of the above-described difference in the deflections we will go back to first principles and deduce the equation for the moment of the mechanical force acting on the needle, taking account of the differences of potential at the surface of contact. As usually stated the energy of charged conductors is

$$W = \tfrac{1}{2}c_1V_1^2 + \tfrac{1}{2}c_2V_2^2 + \tfrac{1}{2}c_3V_3^2 + c_{12}V_1V_2 + c_{23}V_2V_3 + c_{31}V_3V_1 + \cdots \qquad (11)$$

where the V's are the potentials of the conductors, and the c's the coefficients of capacity. If we use the previous notation, it is evident that the energy of the electric field will depend upon the values of the potential just outside the air surfaces of the conductors, *i. e.*, upon $V_1 + \varphi_1$, etc., and not on V_1, etc., alone. Hence the electric energy of n conductors is

$$W = \tfrac{1}{2}\sum_{p=1}^{p=n} c_p(V_p + \varphi_p)^2 + \sum c_{pq}(V_p + \varphi_p)(V_q + \varphi_q) \qquad (12)$$

all possible combinations of p and q being taken once only. In the case of the quadrant electrometer

$$W = \tfrac{1}{2}c_1(V_1+\varphi_1)^2 + \tfrac{1}{2}c_2(V_2+\varphi_2)^2 + \tfrac{1}{2}c_n(V_n+\varphi_n)^2 + c_{12}(V_1+\varphi_1)(V_2+\varphi_2) + c_{1n}(V_1+\varphi_1)(V_n+\varphi_n) + c_{2n}(V_2+\varphi_2)(V_n+\varphi_n). \quad (13)$$

The moment of the force θ tending to increase the deflection θ is the derivative of W with regard to θ, the potentials being kept constant, hence

$$\theta = \tfrac{1}{2}(V_1+\varphi_1)^2\frac{\partial c_1}{\partial\theta} + \tfrac{1}{2}(V_2+\varphi_2)^2\frac{\partial c_2}{\partial\theta} + \tfrac{1}{2}(V_n+\varphi_n)^2\frac{\partial c_n}{\partial\theta} + (V_1+\varphi_1)(V_2+\varphi_2)\frac{\partial c_{12}}{\partial\theta} + (V_1+\varphi_1)(V_n+\varphi_n)\frac{\partial c_{1n}}{\partial\theta} + (V_2+\varphi_2)(V_n+\varphi_n)\frac{\partial c_{2n}}{\partial\theta}. \quad (14)$$

Assume that the quadrants are of the same material, that the needle is connected with the quadrant 1, and that the difference of potential between the quadrants is $E = V_1 - V_2$. Then

$$\varphi_1 = \varphi_2, \quad V_n = V_1 + \varphi_{1n}, \quad \text{and} \quad V_2 = V_1 - E. \quad (15)$$

From the well-known relations between the coefficients (see Maxwell's Electricity and Magnetism, § 219)

$$\frac{\partial c_1}{\partial\theta} + \frac{\partial c_2}{\partial\theta} = \frac{\partial c_n}{\partial\theta}, \quad \frac{\partial c_1}{\partial\theta} = -\frac{\partial c_{1n}}{\partial\theta}, \quad \frac{\partial c_2}{\partial\theta} = -\frac{\partial c_{2n}}{\partial\theta}, \quad \frac{\partial c_{12}}{\partial\theta} = 0. \quad (16)$$

Substituting (15) and (16) in (14) we get

$$\theta_1 = \tfrac{1}{2}\frac{\partial c_2}{\partial\theta}E[E + 2(\varphi_n + \varphi_{1n} - \varphi_1)] + \tfrac{1}{2}\left(\frac{\partial c_1}{\partial\theta} + \frac{\partial c_2}{\partial\theta}\right)(\varphi_n + \varphi_{1n} - \varphi_1)^2 \quad (17)$$

$$= \tfrac{1}{2}\frac{\partial c_2}{\partial\theta}E[E + 2\Phi] + \tfrac{1}{2}\left(\frac{\partial c_1}{\partial\theta} + \frac{\partial c_2}{\partial\theta}\right)\Phi^2;$$

here Φ in the Volta potential difference as before. If the instrument is symmetricaily adjusted

$$\frac{\partial c_1}{\partial\theta} = -\frac{\partial c_2}{\partial\theta}$$

and the last term of (17) vanishes.

If the sign of the electromotive force is reversed

$$\Theta_2 = \tfrac{1}{2}\frac{\partial c_2}{\partial \theta} E[E - 2\Phi] + \tfrac{1}{2}\left(\frac{\partial c_1}{\partial \theta} + \frac{\partial c_2}{\partial \theta}\right)\Phi^2$$

and the two moments differ from each other by

$$\Theta_1 - \Theta_2 = 2\frac{\partial c_2}{\partial \theta} E\Phi.$$

Hence the deflections will be different in the two cases, and this is not caused by lack of symmetry. If we had connected the other quadrants to the needle c_1 and c_2 would have been interchanged in (17), and this would have made a difference in the value of the moments only. For small deflections $\frac{\partial c_2}{\partial \theta}$ is usually constant, and in this case if the instrument is symmetrical (θ being proportional to Θ) (17) reduces to

$$\theta = \frac{k_2}{2} E[E + 2\Phi],$$

which is equation (8).

In the non-symmetrical case the last term of equation (17) simply fixes the position of the zero point as read on the scale when the quadrants were joined together and $E = 0$. So that for small deflections the zero

$$\theta_0 = \tfrac{1}{2}(k_1 + k_2)\Phi^2$$

and

$$\theta_1 = \tfrac{1}{2}k_2 E[E + 2\Phi + \tfrac{1}{2}k_1 + k_2)\Phi$$

and the observed deflection from the zero is

$$\theta = \theta_1 - \theta_0 = \tfrac{1}{2}k_2 E[E + 2\Phi]$$

which is exactly the same as in the symmetrical case.

A similar line of reasoning to the above will apply to every type of electrometer, and it is very important to determine the effect of the Volta potential difference unless it is definitely known that all the conductors of the instrument are of the same material and their surfaces in the same condition.

A better method of measuring the Volta effect than that described above is the following. Place a Clark cell of electromotive force e

in the needle circuit between the quadrants 1 and the needle. This amounts simply to increasing or decreasing the value of the difference of potential between the needle and the quadrants which before was φ_{1n}. The formula under these circumstances becomes

$$\theta_1 = \frac{k}{2} E[E + 2\Phi \pm 2e] \tag{18}$$

and the difference in deflection on reversing E is

$$\theta_1 - \theta_2 = 2kE(\Phi \pm e) = K[\Phi \pm e], \tag{19}$$

since we may assume $\frac{\partial e_1}{\partial \theta}$ to be constant over the small range of deflections $\theta_1 - \theta_2$. Experiments with the above described electrometer gave the results tabulated below.

	θ_1	θ_2	$\theta_1 - \theta_2$	Φ(Volts).
No Clark cell.	24.75	22.20	2.55	.956
Positive pole to needle	26.54	20.32	6.22	.902
Negative pole to needle	22.86	24.26	−1.40	.905

The values of Φ were calculated by substituting in equation (19) and eliminating K. The temperature was 20° C., and the value of $e = 1.430$ volts.

The fact that the Volta potential difference increased enormously on simply cleaning the air surfaces of the needle while the metal contacts were left undisturbed is strong evidence for the view that most of this difference of potential is due to impressed electromotive forces in the air surfaces and not, in the metal contacts.

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A FURTHER NOTE ON THE VISIBLE RADIATION FROM CARBON.

BY EDWARD L. NICHOLS AND ERNEST BLAKER.

THE present writers have in two recent papers[1] shown the existence of a selective radiation from glowing carbon, which manifests itself in the region lying between the yellow and red. When the latter of these papers were read at the Denver meeting of the American Association for the Advancement of Science, Professor D. B. Brace suggested that this peculiarity might be connected with the anomalous dispersion of carbon noted by previous investigators. It is the object of this note to call attention to the fact that the optical properties of carbon are such as one would naturally expect to find in accompaniment with selective radiation in the given region.

While it is hardly safe to deduce from the optical behavior of a substance at ordinary temperatures its properties when heated to incandescence, it is obvious that one would expect, in so far as those properties are unchanged by the rise of temperature, that in the region where the emission curve shows a maximum there would be an absorption band and that in the neighborhood of this absorption band anomalous dispersion might be looked for. In point of fact there is evidence from measurements already published that the absorption of light by thin films of carbon is greater in the middle of the visible spectrum than in the red or violet. In 1886 one of the present writers[2] published the results of measurements upon the spectrum of two specimens of lampblack, both of which showed a greater transmitting power in the red and the violet than in the region of the D line. The maximum of absorption was found to lie in the neighborhood of the E line ($\lambda = .52\mu$). The color of lampblack was described as *a purple in which red is the dominant hue, but in which violet also greatly predominates over the wave-lengths which form the central region of the visible spectrum.* Measurements upon the age coating in incandescent lamp bulbs, made by Messrs. Moore and Ling in 1892,[3] show that the absorption of light by the deposit of carbon upon

[1] Nichols: The Visible Radiation from Carbon; PHYSICAL REVIEW, Vol. XIII., page 65 (1901); also Blaker, ibid., p. 345.

[2] Nichols: Trans. of the Kansas Academy of Science, Vol. X., page 37.

[3] Nichols: American Journal of Science, Vol. XXXIV., page 277.

the bulb of a lamp with treated filament, after 908 hours, is greatest in the region of .635μ.

The curve given in Fig. 1 is plotted from their data. It is noteworthy that the maximum of absorption as indicated in this curve corresponds very closely with the maximum of radiation in the intensity curves published in our recent papers. (See Fig. 2, page 138 and Fig. 16, page 357, Vol. XIII. of the PHYSICAL REVIEW.) Knut Ångström,[1] in his paper on the transmission of heat of various wave-lengths through turbid

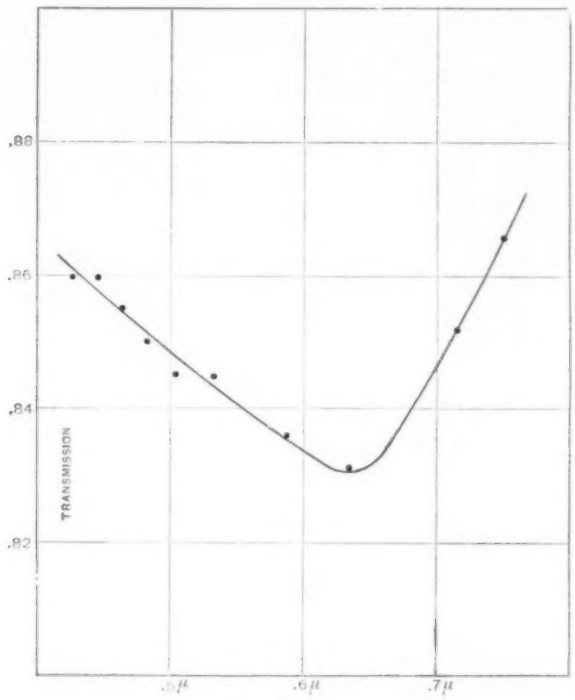

Fig. 1.

media, explored the infra-red spectrum of lampblack. While his curves do not extend into the visible spectrum, they show the rapidly increasing opacity of this substance as the limit of visibility in the red is approached; and it is evident that we have to do here with one side of an absorption band which in the case of thick layers, at least, covers the entire spectrum. Sudden changes from opacity to transparency like that exhibited by carbon are usually indicative of anomalous dispersion and in point of fact Wood has recently[2] described measurements upon prisms of lampblack and layers of carbon deposited upon glass from the

[1] Ångström: Wiedemann's Annalen, Vol. 36, page 715 (1889).

[2] Wood: Philosophical Magazine 6, Vol. I., page 405 (1901).

filament of an incandescent lamp, which exhibited this peculiarity. It would thus appear that there is abundant experimental evidence of the existence of all those optical peculiarities in carbon which would naturally accompany the phenomenon described in our papers cited at the beginning of this note. Since the existence of a maximum of absorbing power in the middle of the visible spectrum does not appear to be universal in carbon films, neither Rosicky[1] nor Stark[2] having noted this peculiarity in their spectrophotometric studies of lampblack and Moore and Ling in their measurement of the age coating in incandescent lamps having found this maximum in a coating from a treated filament, but not in that from an untreated lamp, it has seemed worth while to make further measurements both of the absorption and dispersion of carbon.

The present writers have in hand an investigation of this character the results of which are not yet ready for presentation; but it may be stated in this connection that the spectrophotometric study of a film of carbon deposited upon glass by the method described by Wood gave indications of maximum of absorption in the region .52 μ and that measurements of the dispersion of a prism of asphalt, the optical properties of which substance, as will be shown in a forthcoming paper, are so nearly identical with those of carbon as to lead to the conclusion that the color of this substance is due to carbon particles suspended in a translucent medium consisting of hydrocarbons, gave the following results:

TABLE I.

Anomalous Dispersion in Asphalt.

Wave-Length.	Index of Refraction.
.6708 μ	1.6209
.6104 μ	1.6282
.5896 μ	1.6351
.5682 μ	1.6339

These indices are much smaller than those found for carbon by Stark and by Wood as was to have been expected in the case of what may perhaps be regarded as a solid solution of carbon in a medium of smaller refractive power. The measurements would seem to indicate that the maximum of the absorption band corresponding to this region of anomalous dispersion occurs at a somewhat shorter wave-length than in the case of the carbon film studied by Moore and Ling and of the carbons used by the present writers in their measurements upon the emissive power of that substance.

PHYSICAL LABORATORY OF CORNELL UNIVERSITY,
Nov. 27, 1901.

[1] Rosicky: Wiener Berichte, 78, II., page 407 (1878).
[2] Stark: Wiedemann's Annalen, 62, page 351.

NEW BOOKS.

High Temperature Measurements. By H. Le Chatelier and O. Boudouard. Translated by George K. Burgess. New York, John Wiley & Sons, 1901. Pp. xi + 230.

Mr. Burgess in this volume has given us an excellent translation of the well-known work of Le Chatelier and Boudouard and he has in addition brought the subject up to date by means of a chapter of his own entitled "Recent Developments," in which the latest advances in pyrometry have been recorded. It is a great convenience to workers in this field to have in convenient form such data as those upon the expansion of nitrogen by Chappius and Harker and the results of Holborne and Day upon air thermometers. The establishment of the fact that bulbs of platinum-iridium although permeable to hydrogen are impervious to nitrogen even at a white heat is of great importance. The determinations of these authors of the melting points of silver, gold, and copper would seem to leave but little to be desired, and it is a matter of gratification to find that the art of making the platinum metals has now reached a stage in which thermo elements for high temperatures give consistent results. The bibliographical index at the close of Mr. Burgess's translation is much fuller than that in the original French edition of this work.

E. L. N.

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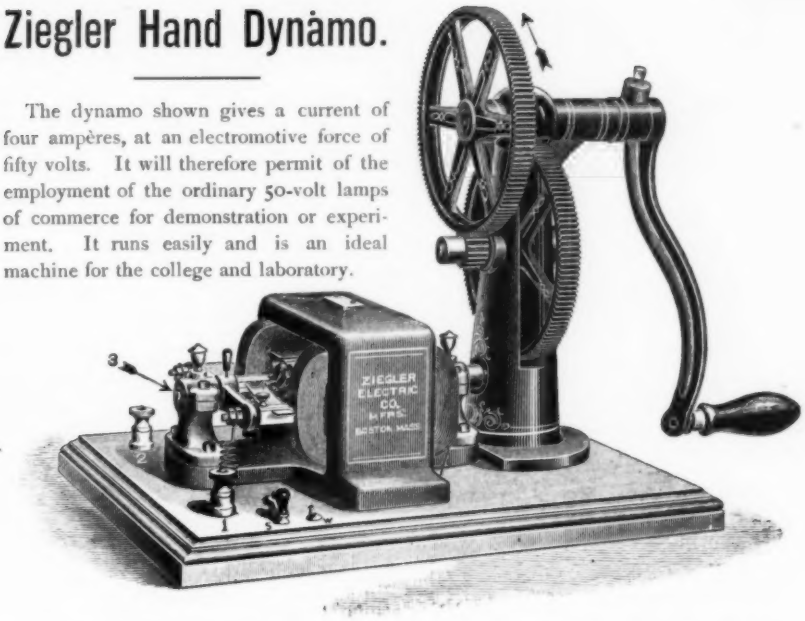

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